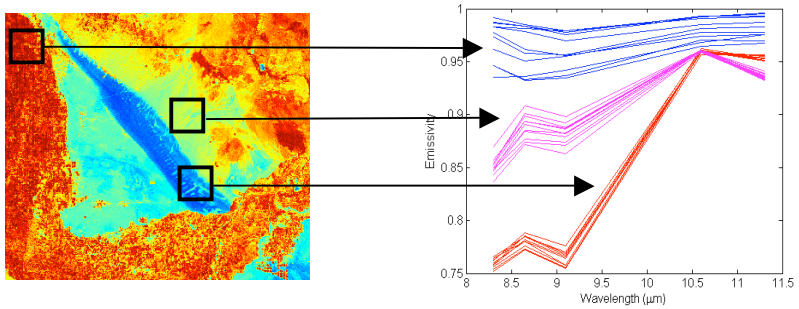
Jet Propulsion Laboratory
California Institute of Technology

An Intercomparison of AIRS, MODIS, and ASTER Land Surface Temperature and Emissivity (LST&E) Measurements



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AIRS Science Team Meeting, April 15-17, 2008, Caltech, Pasadena, CA

LST&E Intercomparison Goals

• International Workshop on the Retrieval and Use of Land Surface Temperature: Bridging the Gaps – Asheville, NC, 7-9 April `08

• What are the natural spatial and temporal scales of the natural variability of the relevant quantities (LST&E)?

• To what degree can we identify BIASES in the LST&E products?

• When product algorithm changes are made (i.e. version changes), do we have a way of deciding if the intended improvements actually improve or degrade the product accuracy?

• More research and validation on low emissivities over barren areas

• Set of core validation LST&E sites over homogenous areas - set standard to which remote sensing LST&E measurements compared

• A possible Unified LST&E product for Earth Science Research?

MODIS, AIRS, ASTER LST&E Climate Product Characteristics

Potential Sources of Bias and Mitigation Approaches

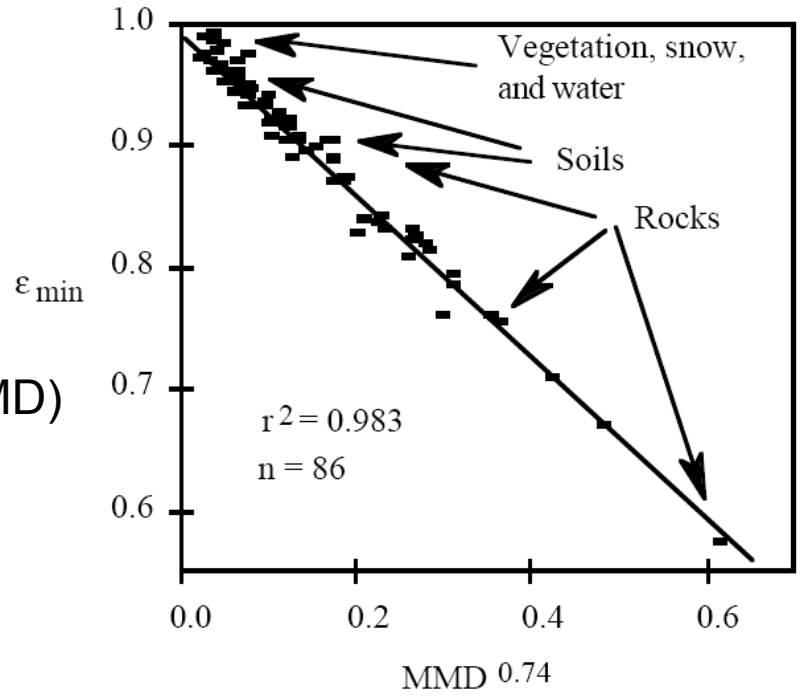
	Aqua **MODIS**	Aqua **AIRS**	Terra **ASTER**
Sensor Calibration	< 0.2 K (windows)	< 0.2 K	< 0.3 K
Atmospheric Attenuation	Column Retrieved	Profile Retrieved	Column Retrieved
Cloud Contamination	Cloud Detection	Cloud Clearing	Cloud Detection
Surface Type	Day/Night (004) Land Cover Class (005)	Multi-spectral	Calibration Curve
Temporal Sampling	Clear only; 1:30 AM, PM Twice daily	Partly Cloudy; 1:30 AM, PM Twice daily	Clear only 10:30 AM, PM every 16 days
Spatial Sampling and Resolution	1 km Clear Only (1 km –> 5 km)	45 km CC (15 km –> 45 km)	90 m Clear only
Scan angle	± 55°	± 45°	± 8.55°

ASTER Temperature Emissivity Separation (TES) Algorithm

- Inversion of T and ε are underdetermined
- In TES, additional constraint arises from minimum emissivity vs spectral contrast
- Observed maximum-minimum difference (MMD) used to obtain unknown emissivity value
- Three error sources:
  - Reliance on empirical function
  - Atmospheric corrections (~1 K)
  - Radiometric calibration errors (small)
- Reported accuracy:
  - T within 1.5 K and ε within 0.015 (1.5%)

• **Strength:** low emissivity, high spectral contrast

• **Weakness:** high emissivity, low spectral contrast



$$\varepsilon_{min} = 0.994 - 0.687 * MMD^{0.74}$$

ASTER TIR Bands

Band 10	8.125 – 8.475 μm
Band 11	8.475 – 8.825 μm
Band 12	8.925 – 9.275 μm
Band 13	10.25 – 10.95 μm
Band 14	10.95 – 11.65 μm

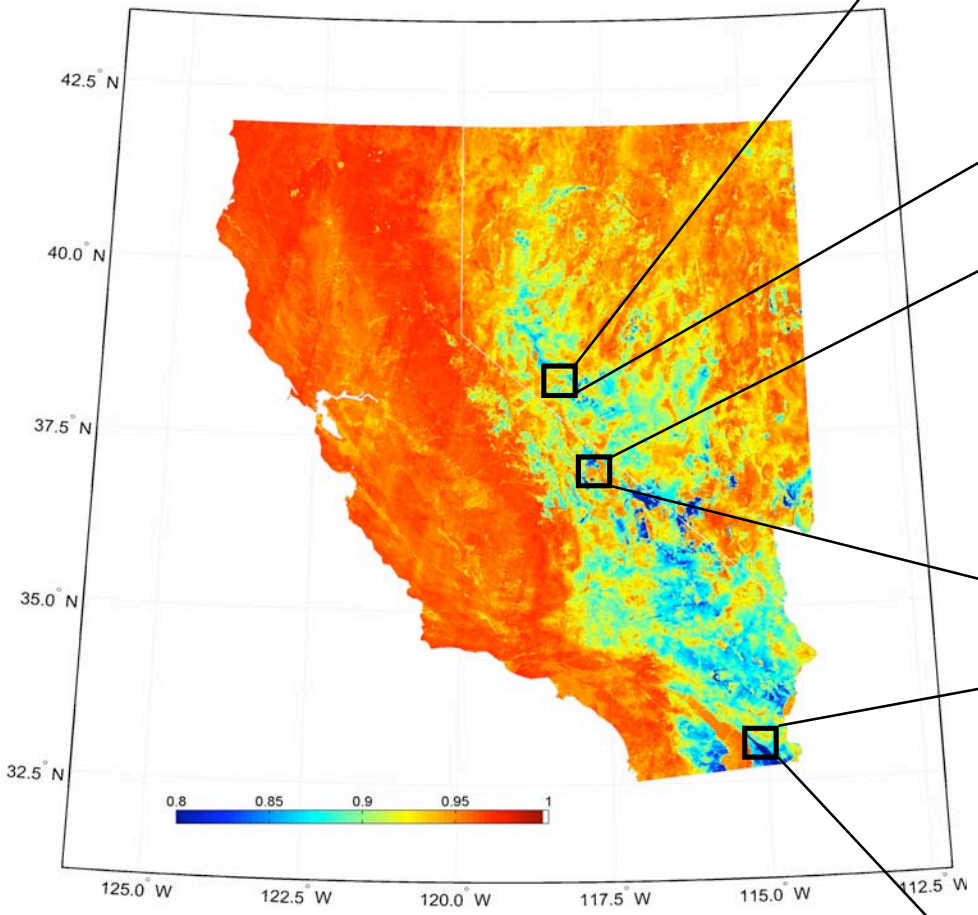
ASTER Gridded L3 Emissivity Product

- Mean Summer (July, Aug, Sep) and Winter (Jan, Feb, Mar) emissivity from 2000-2008
- ASTER Land Surface Emissivity Aggregation Algorithm (ALSEA)
- Use New ASTER Cloud Mask (NACMA) to screen out cloudy pixels (MODIS/AVHHR/Landsat)
- Determine all intersecting granules on 1°x1° given grid
- Output mean and temporal SDev for all clear obs on each pixel
- 100 m spatial resolution
- States completed:
  - California, Nevada, Arizona, Utah, New Mexico, Oklahoma, Texas
- Complete USA by end of year??

** **Hulley, G.**, S. J. Hook, 2008, The ASTER Land Surface Emissivity Database of California and Nevada, *Geophys. Res. Lett.*, in review.

ASTER Validation Sites

- Rocks and Sand



Cuprite, NV (03/26/08)

Carbonate

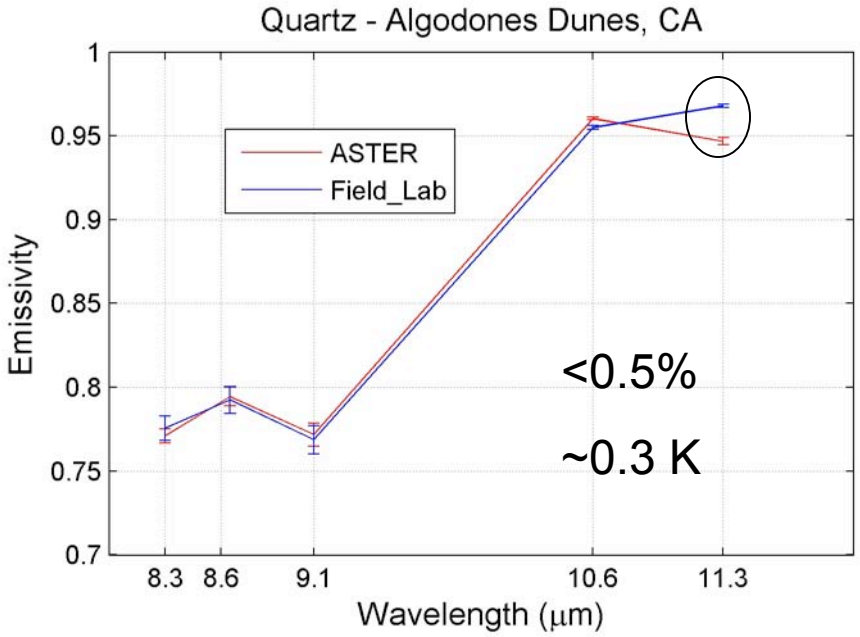
Stovepipe Wells Dunes (03/27/08)

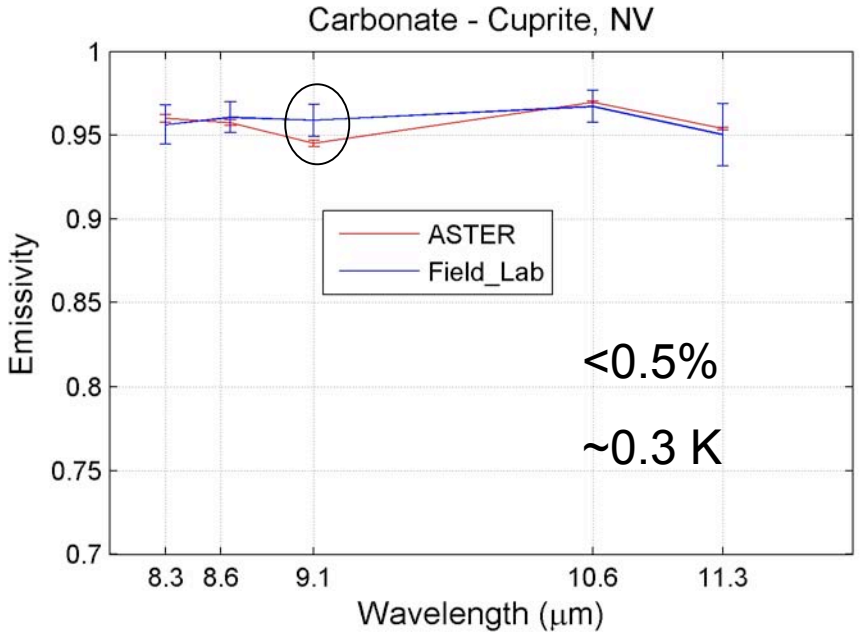
Algodones Dunes (03/24/08)

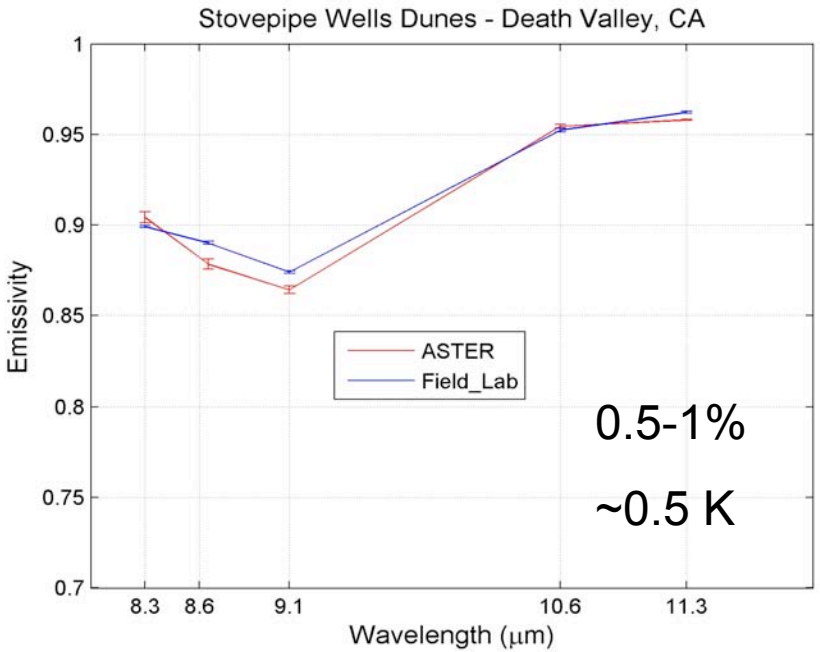
Quartz

10 samples at each site over 500m² area

2x2 ASTER pixels (100 m) averaged over each sample

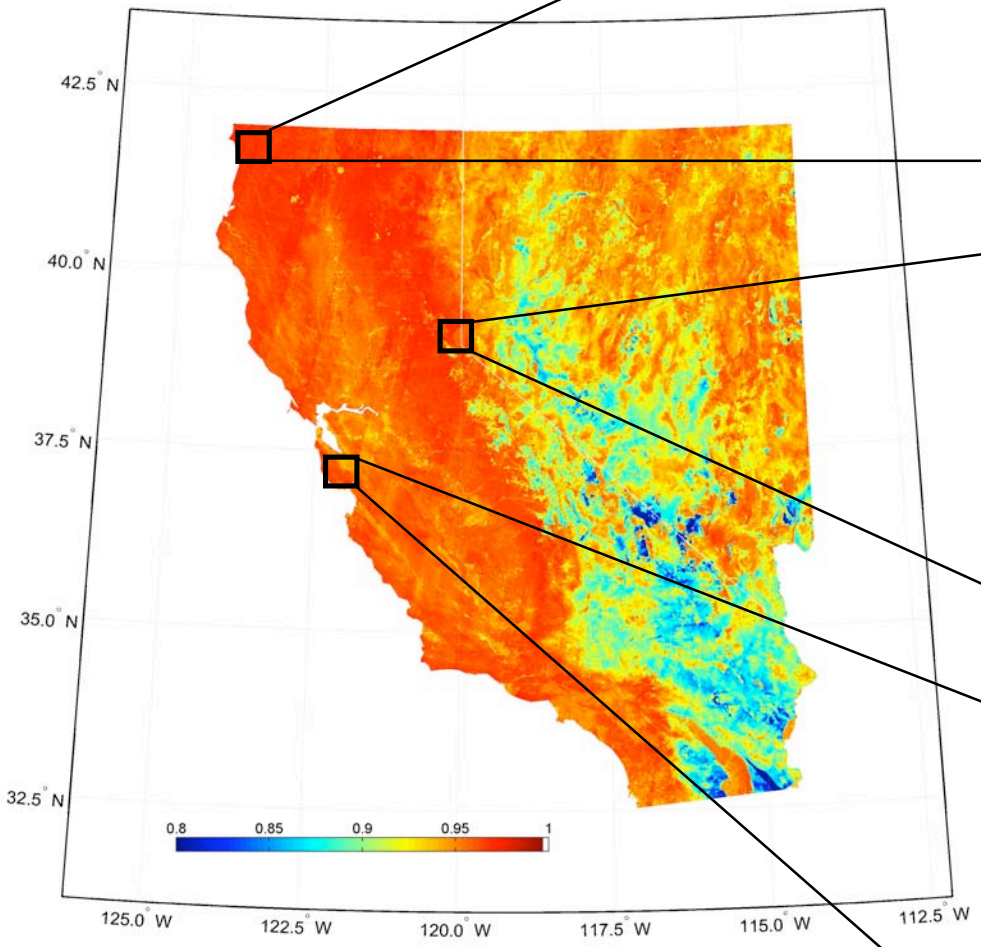

Quartz - Algodones Dunes, CA
Emissivity
Wavelength (μm)
ASTER
Field_Lab
<0.5%
~0.3 K


Carbonate - Cuprite, NV
Emissivity
Wavelength (μm)
ASTER
Field_Lab
<0.5%
~0.3 K


Stovepipe Wells Dunes - Death Valley, CA
Emissivity
Wavelength (μm)
ASTER
Field_Lab
0.5-1%
~0.5 K

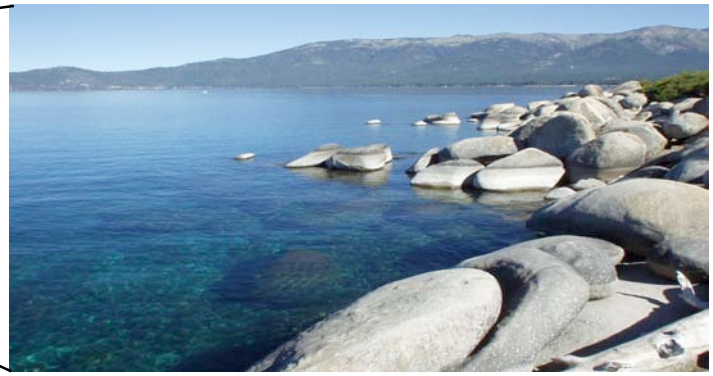
ASTER Validation Sites

- Vegetation and Water

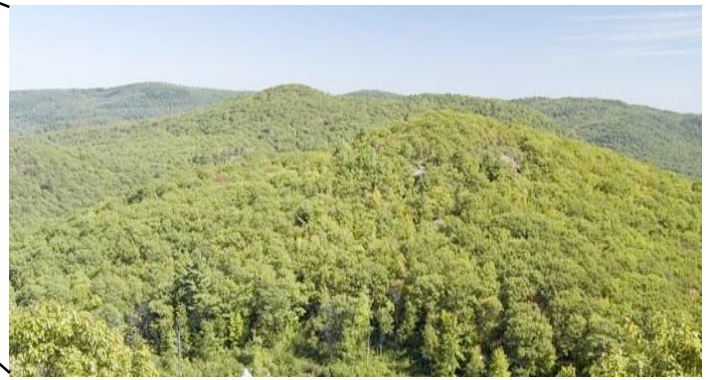


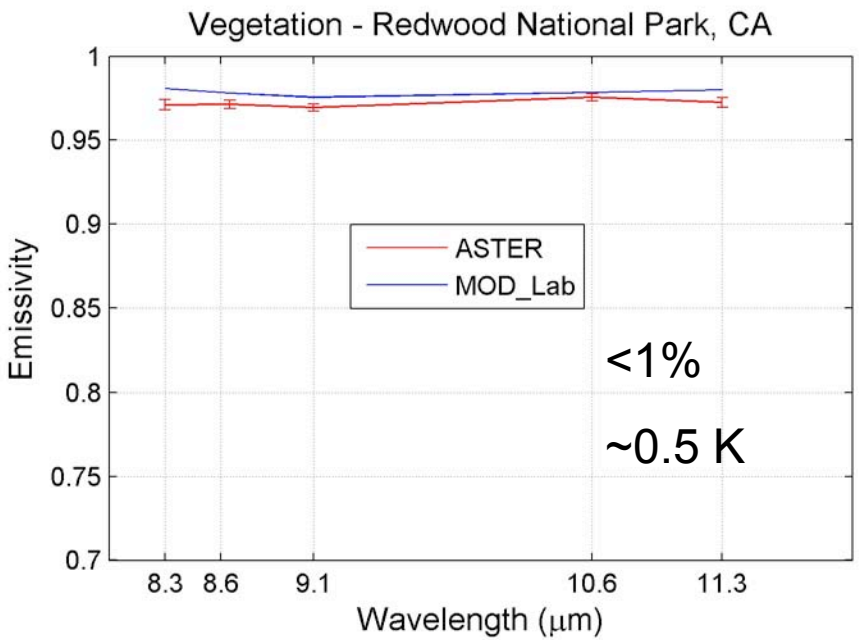
Redwood National Park – Conifer Forest

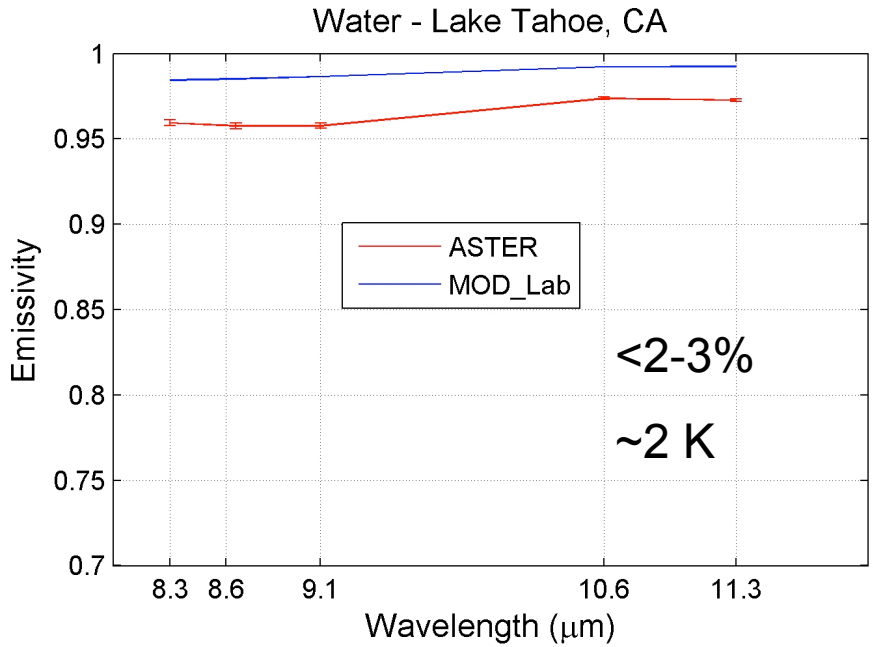
Lake Tahoe - Water



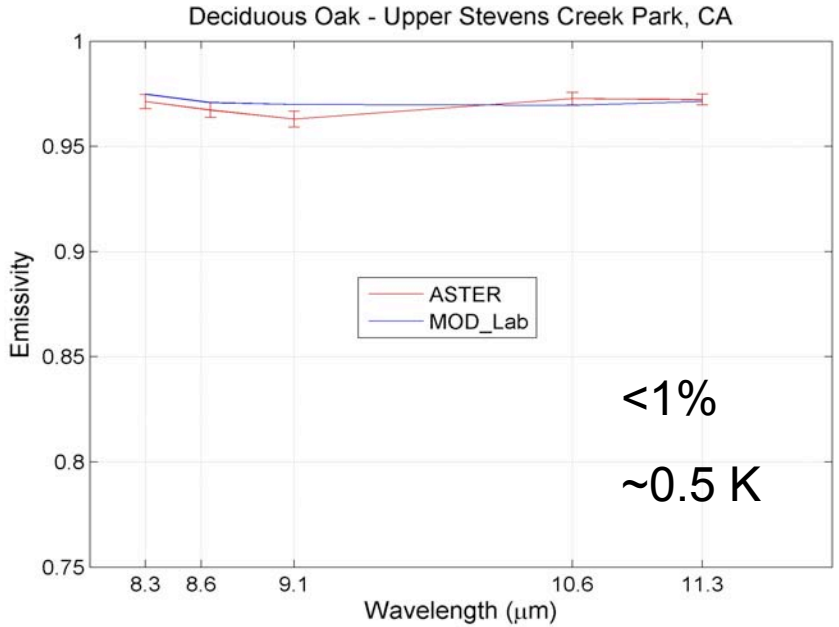
Stevens Creek Oak Forest - Deciduous







MODIS UCSB
spectral library



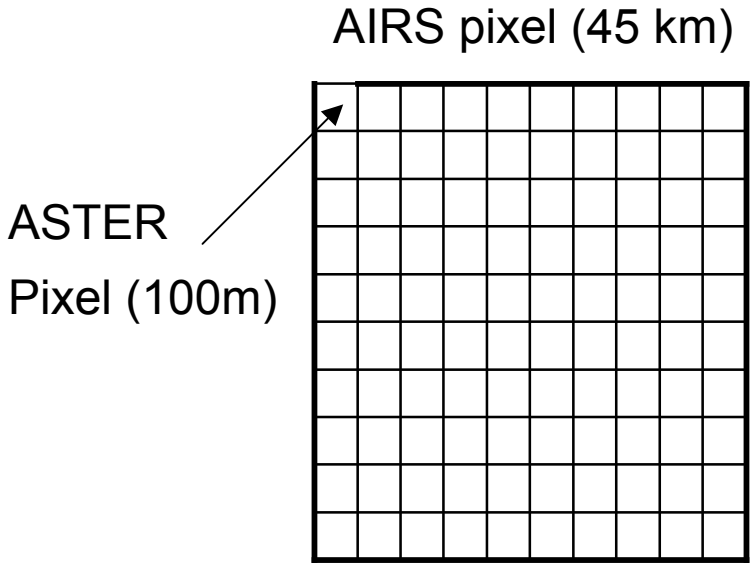
Sampling data with different spatial resolutions

Current:

$$\bar{e} = \frac{1}{n}\sum_{k=1}^{n} e_k$$

Proposed:

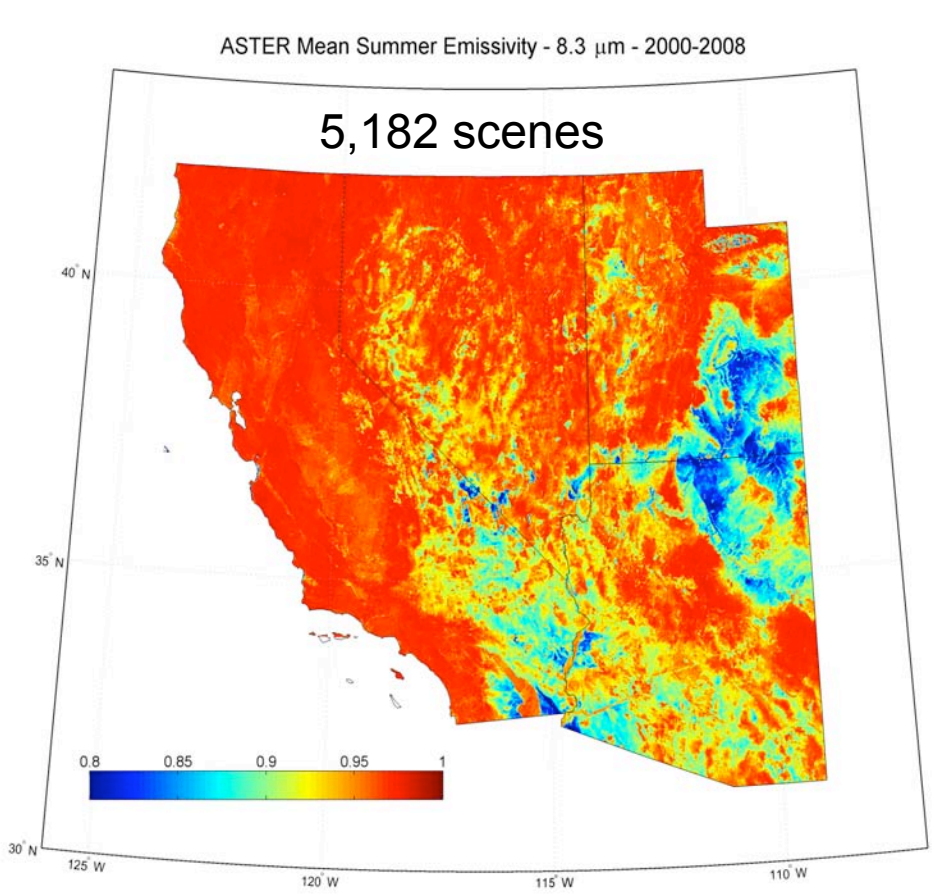
$$\bar{e} = \left[\frac{\frac{1}{n}\sum_{k=1}^{n} e_k B(T_k)}{B(T^*_{AIRS})} \right]$$

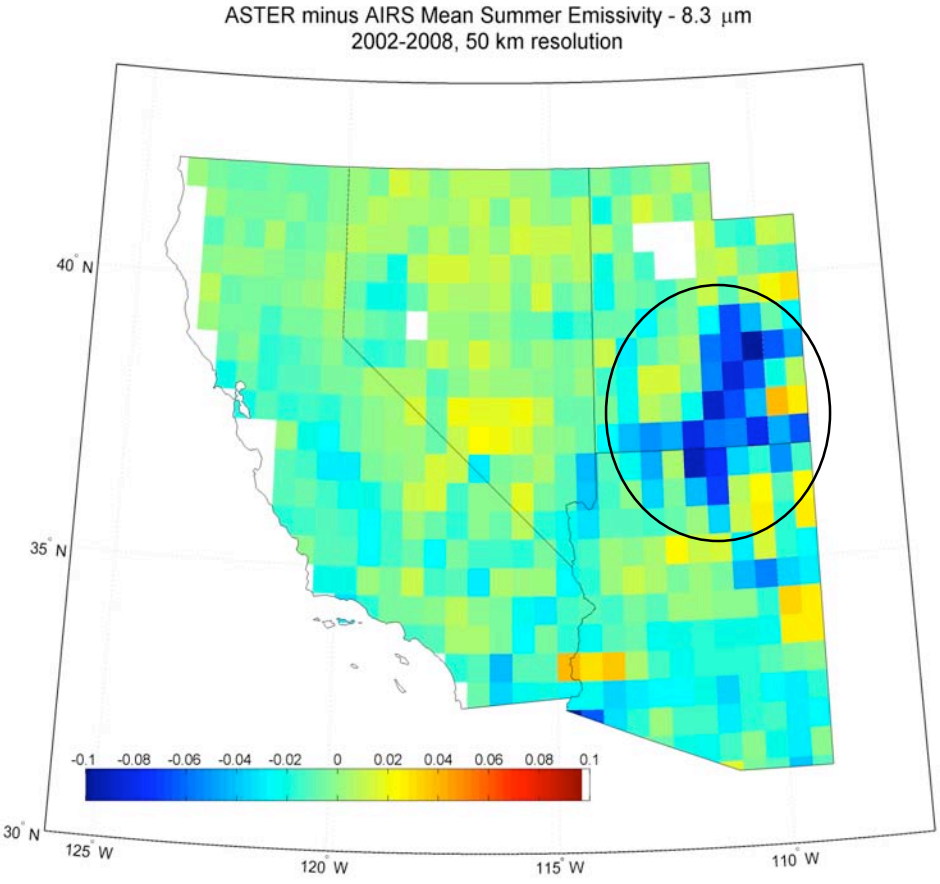


** But ASTER product is mean, seasonal T and e

Work in progress…..

ASTER minus AIRS (v5) Mean Summer Emissivity Differences



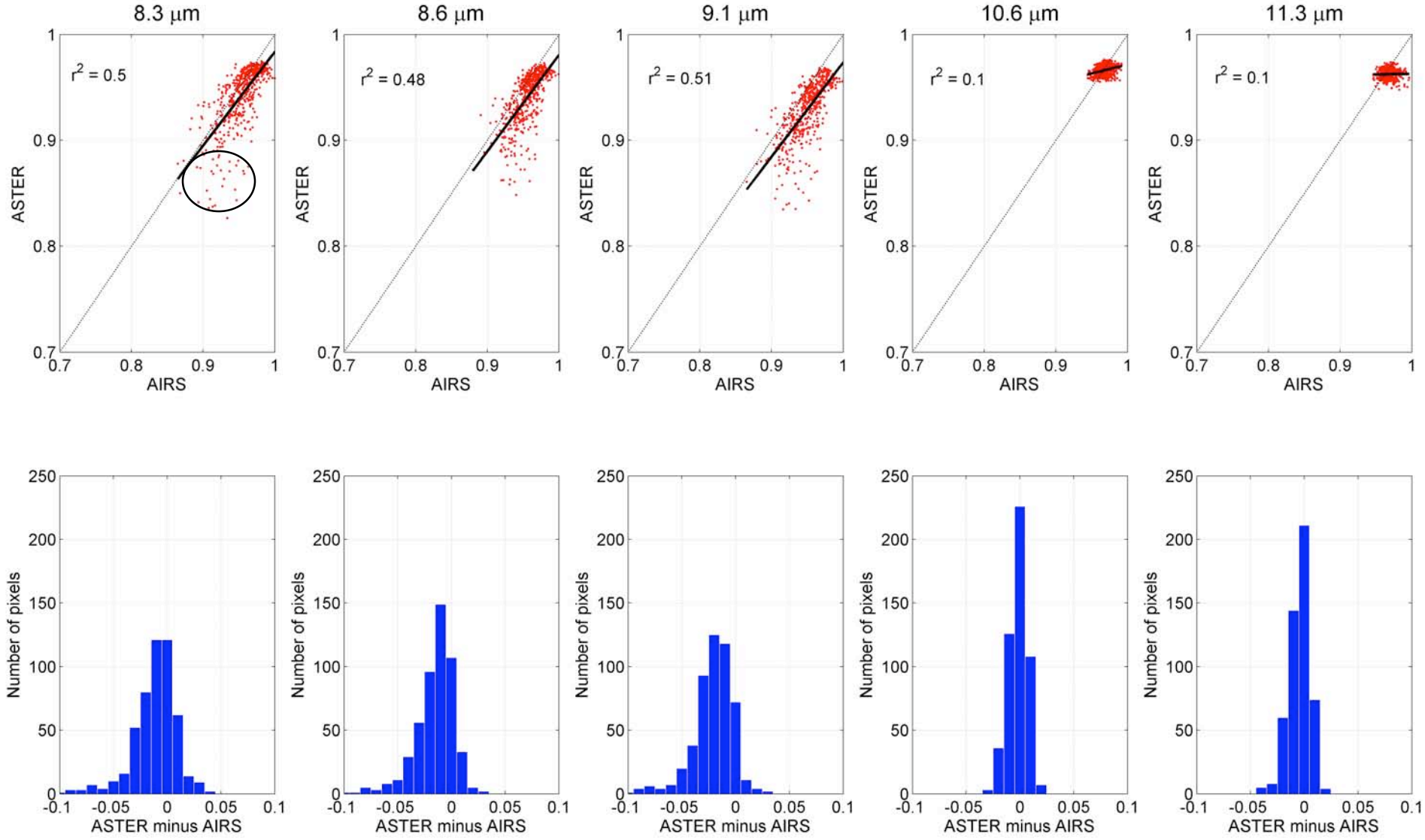


** 80% of pixels have less than 1.5% emissivity difference (~1 K)

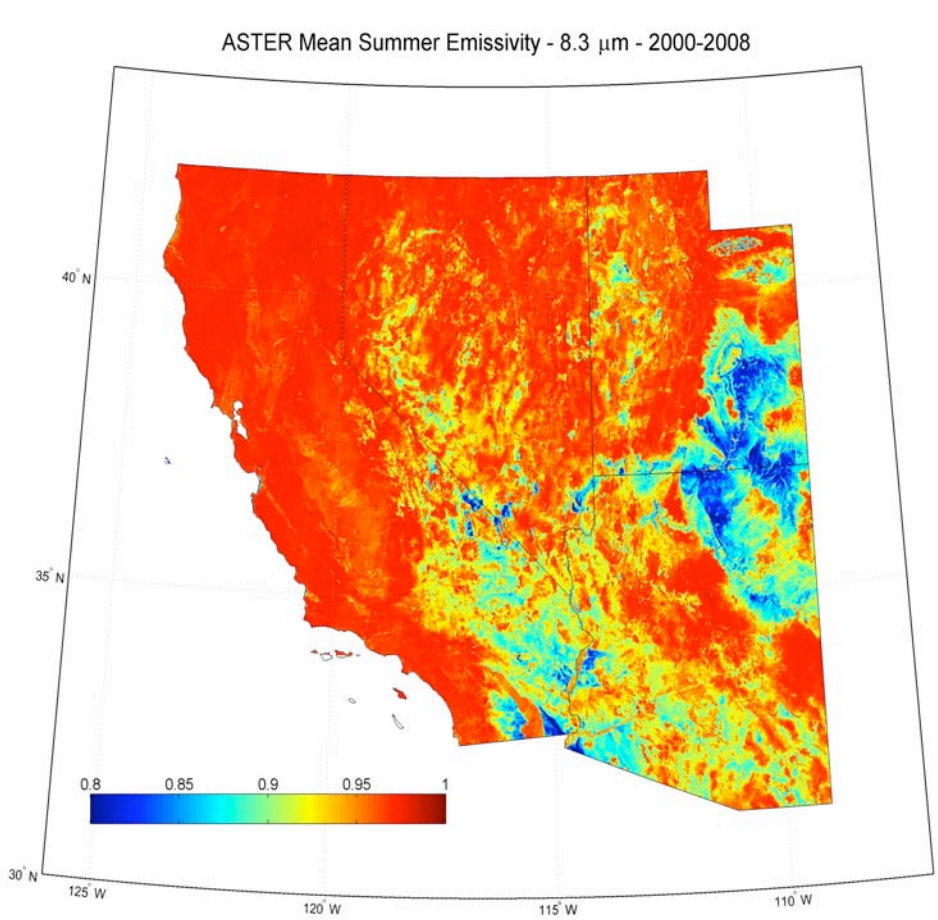
** Low emissivity areas have differences up to 7% (6.5 K)

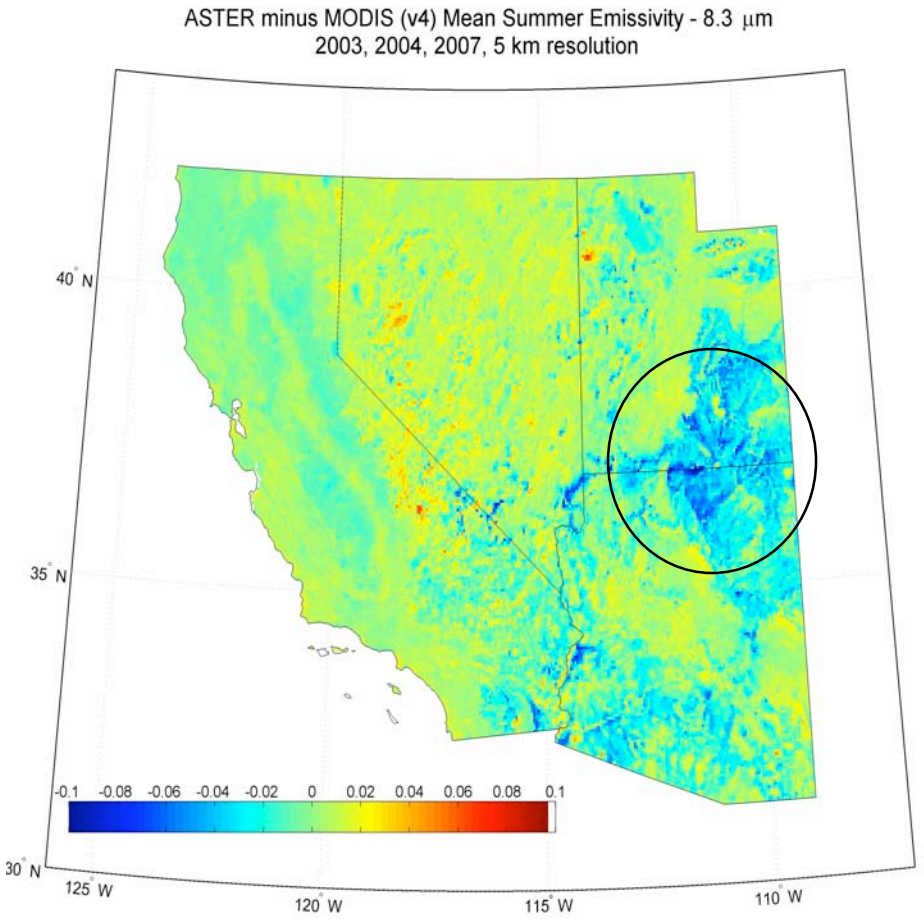
But could be due to AIRS overestimating nighttime emissivities over barren areas

ASTER and AIRS Emissivity Comparisons for all 5 TIR bands



ASTER minus MODIS (MYD11C3 V4) Mean Summer Emissivity Difference

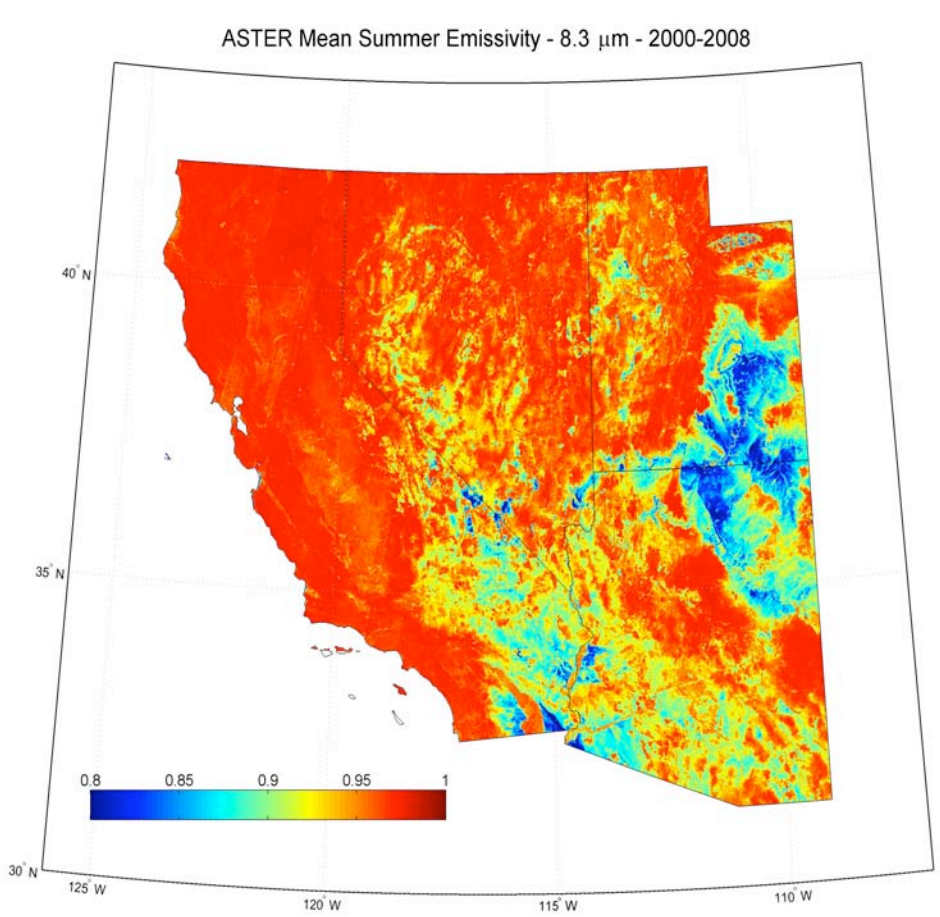


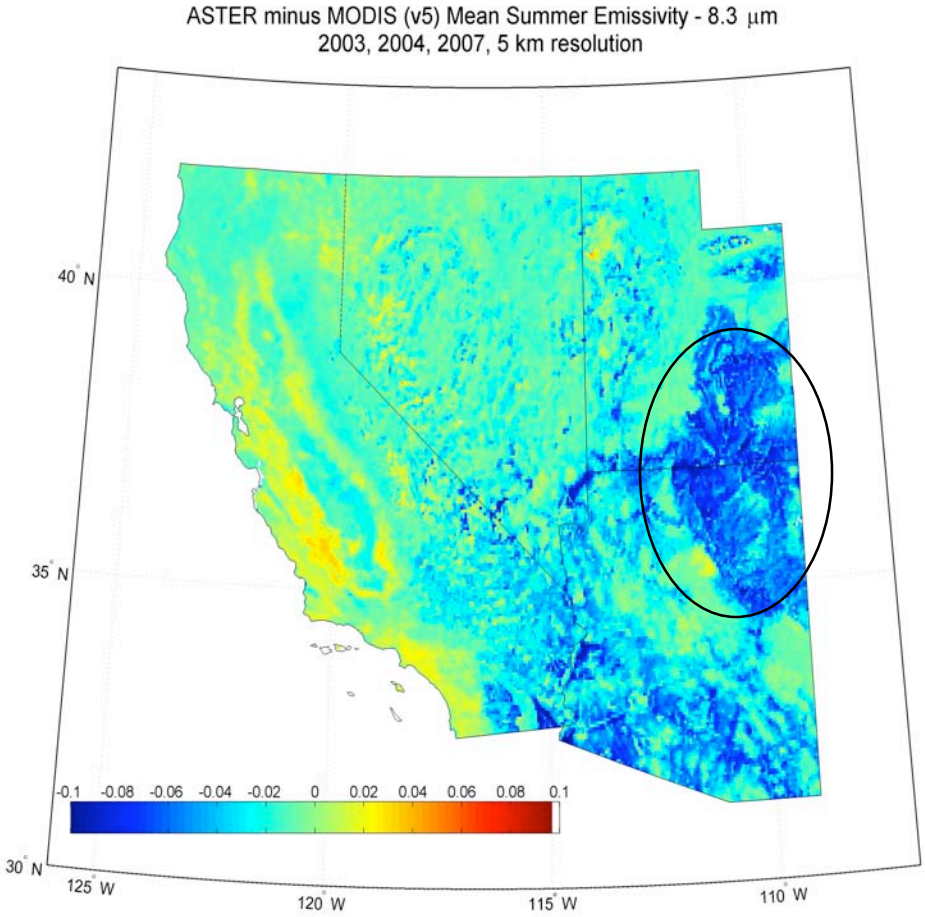


** 80% of pixels have less than 1% emissivity difference (~0.8 K)

** Low emissivity areas have differences up to 6% (~5.6 K)

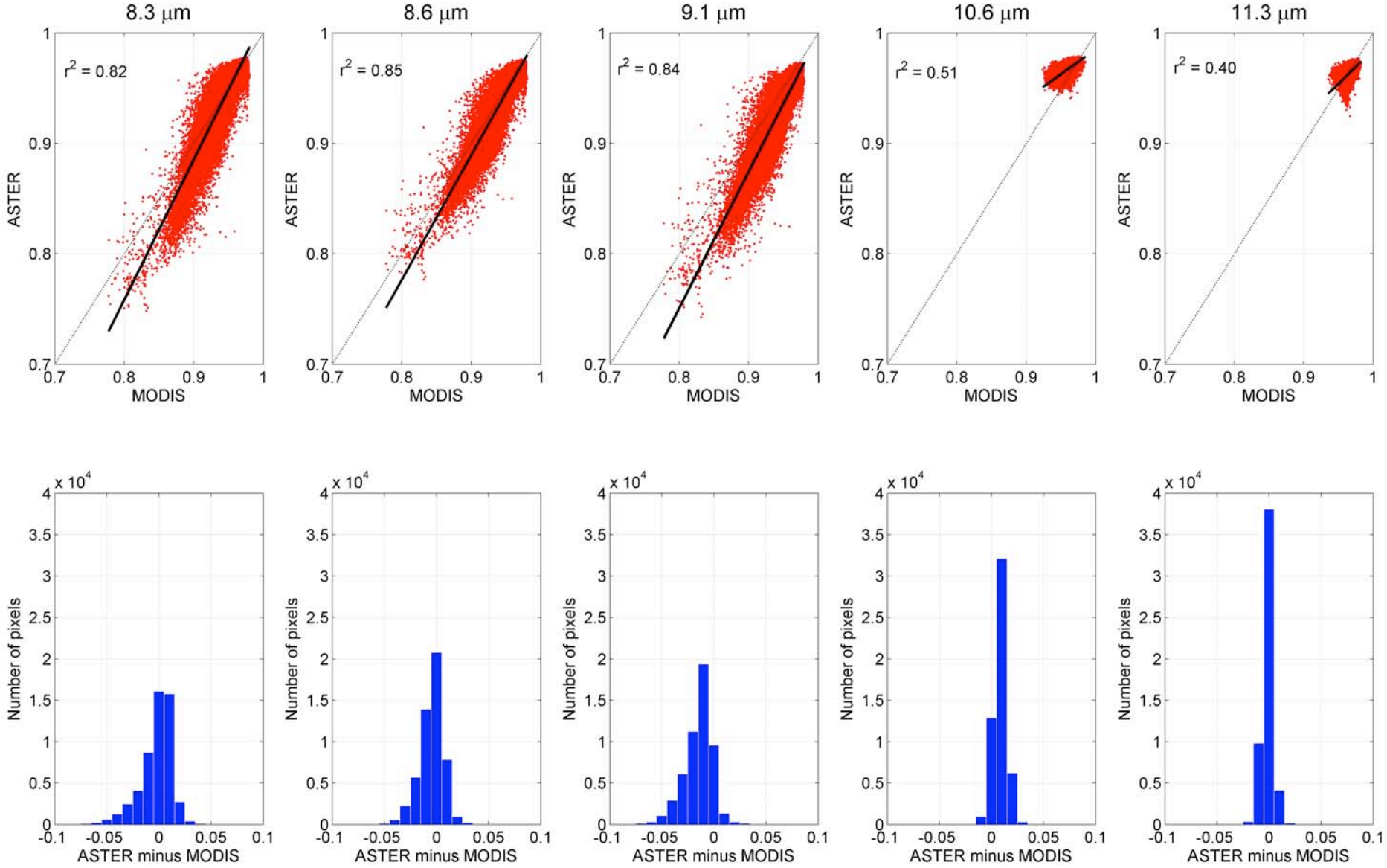
ASTER minus MODIS (MYD11C3 V5) Mean Summer Emissivity Difference



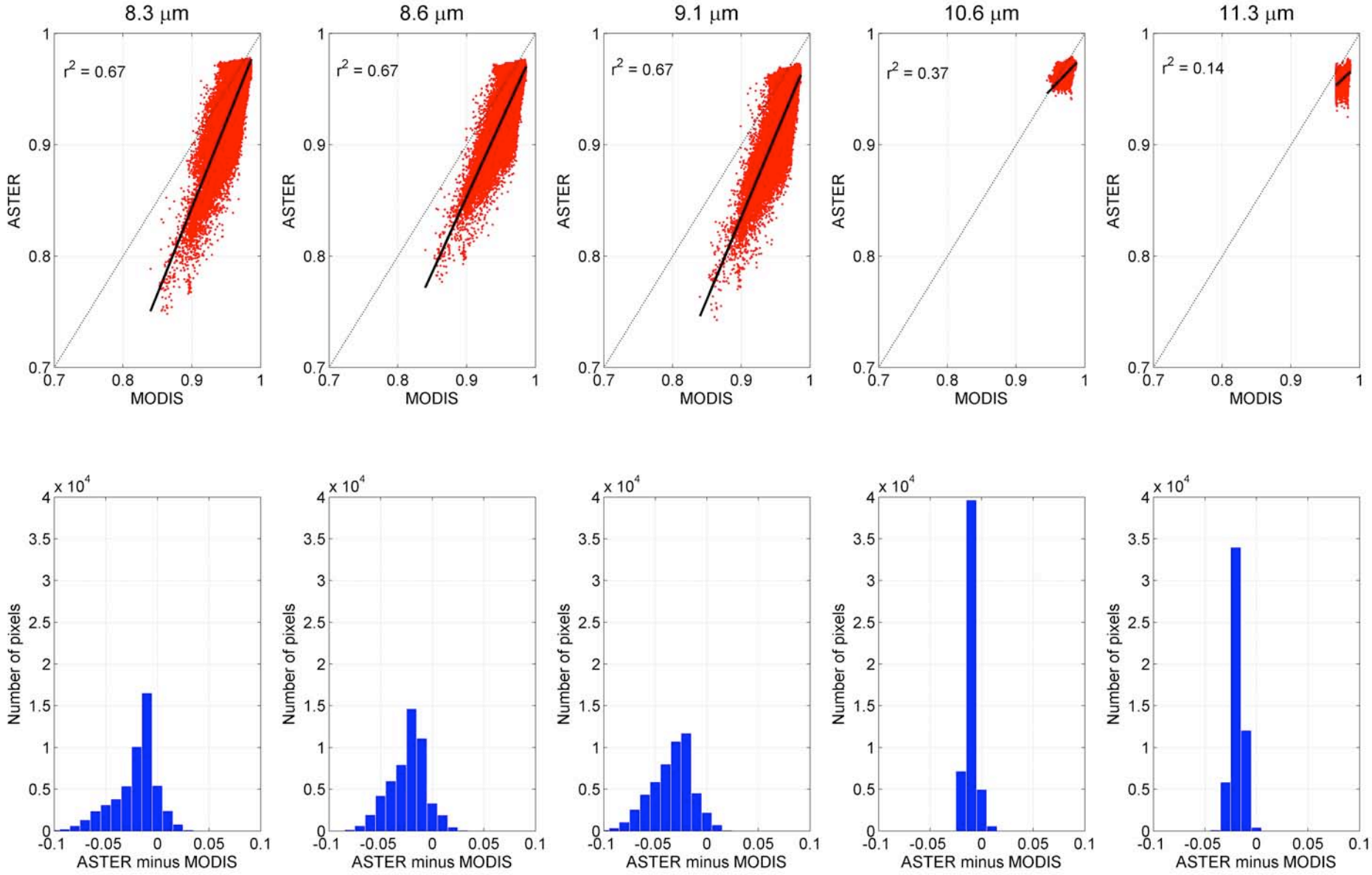


- MODIS (v5) uses Day/Night combined with Split-Window Land Cover type
- **Up to 10% emissivity difference in arid/semi-arid areas!! (~9 K)**

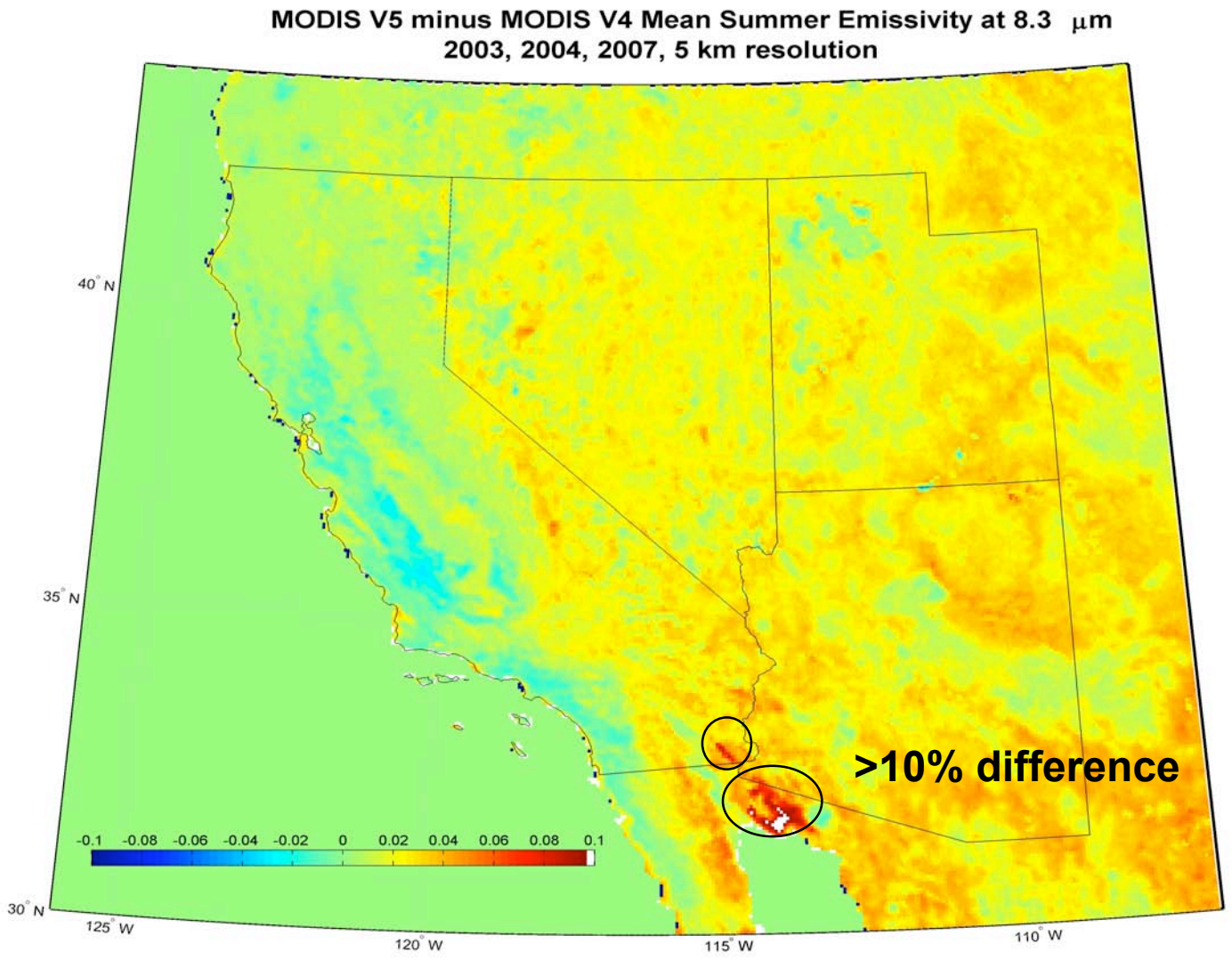
ASTER and MODIS (v4) Emissivity Comparisons for all 5 TIR bands



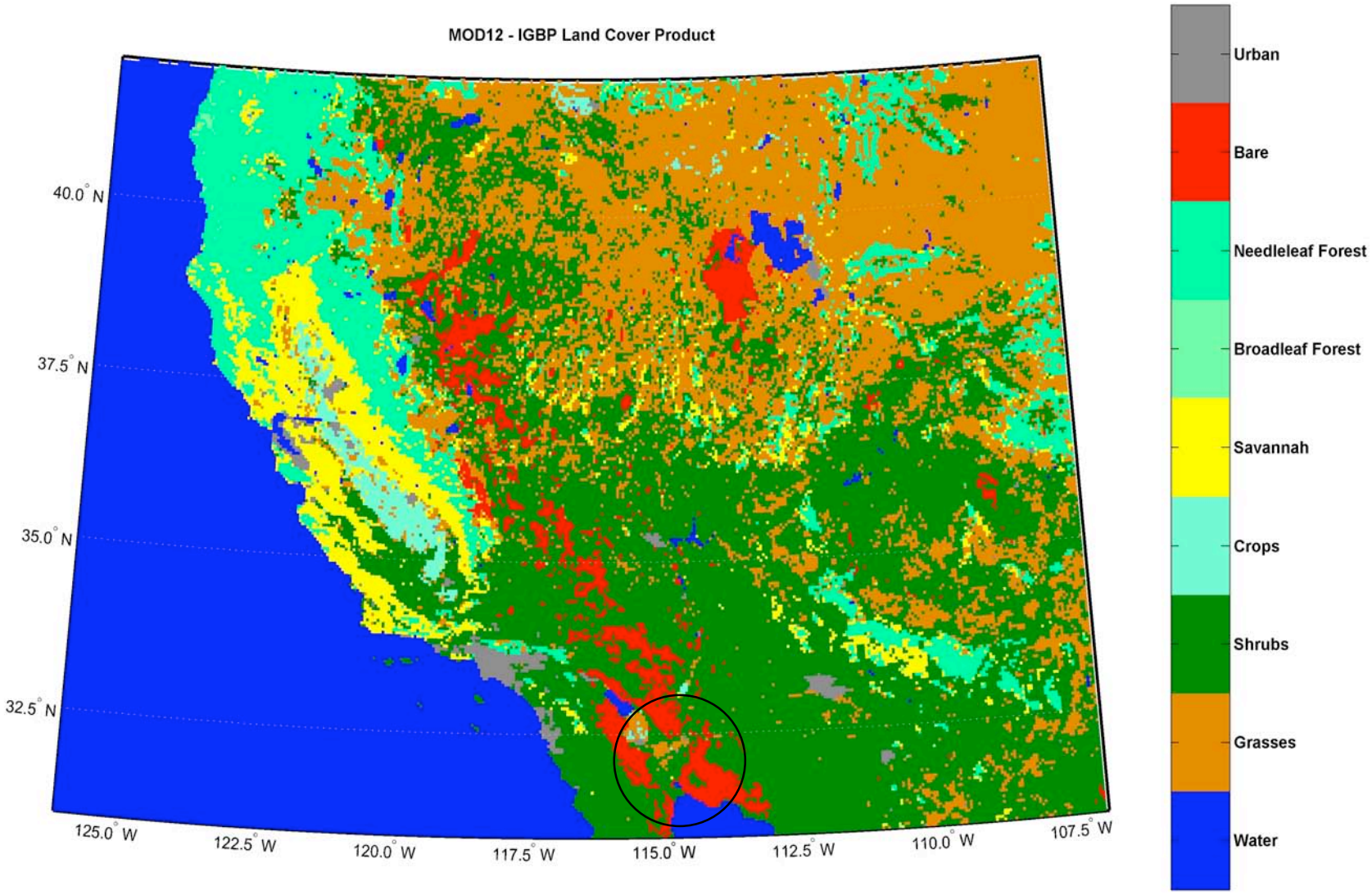
ASTER and MODIS (v5) Emissivity Comparisons for all 5 TIR bands



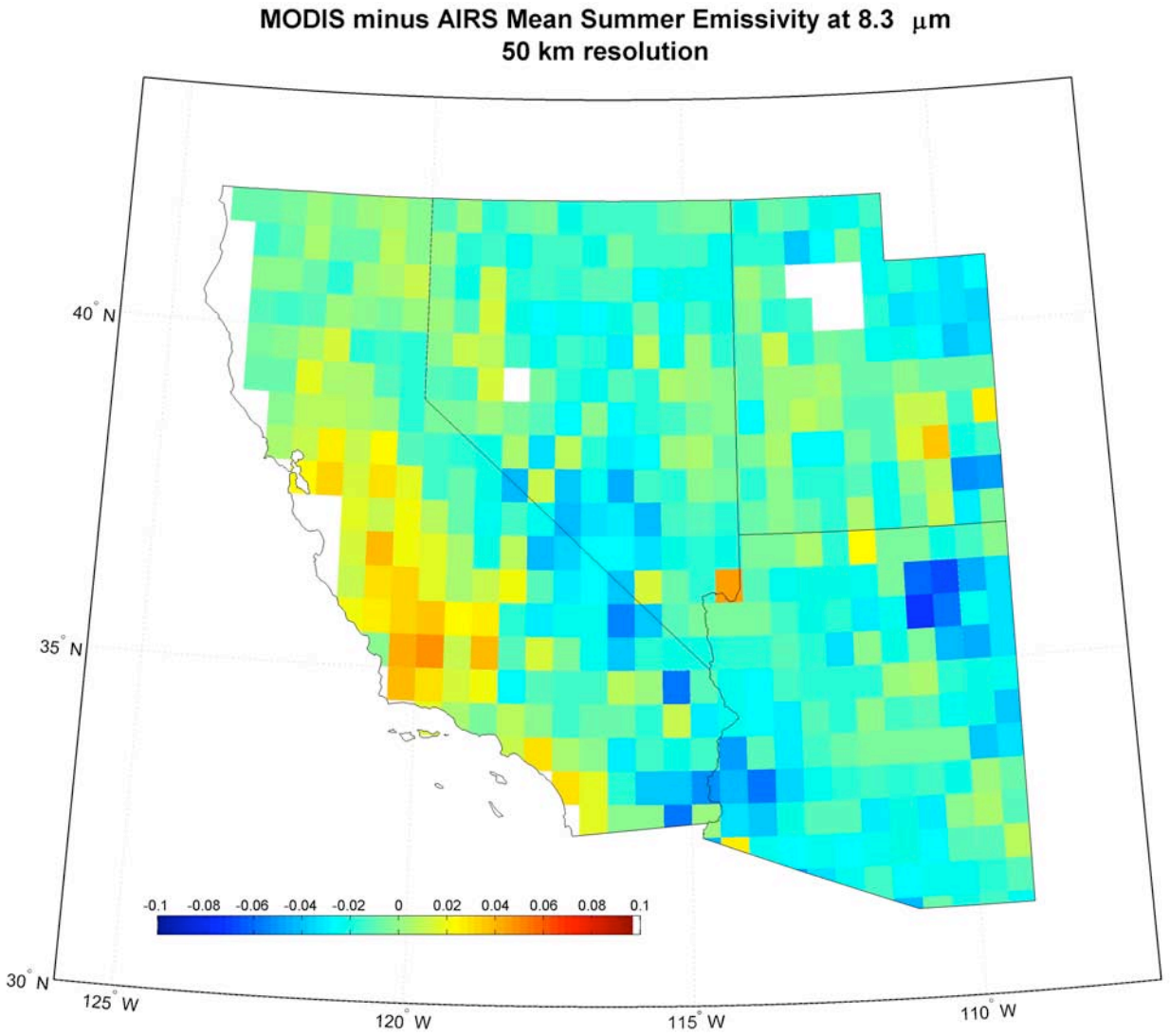
MODIS (v5) and MODIS (v4) Emissivity Difference at 8.3 µm



MODIS IGBP Land Cover Product



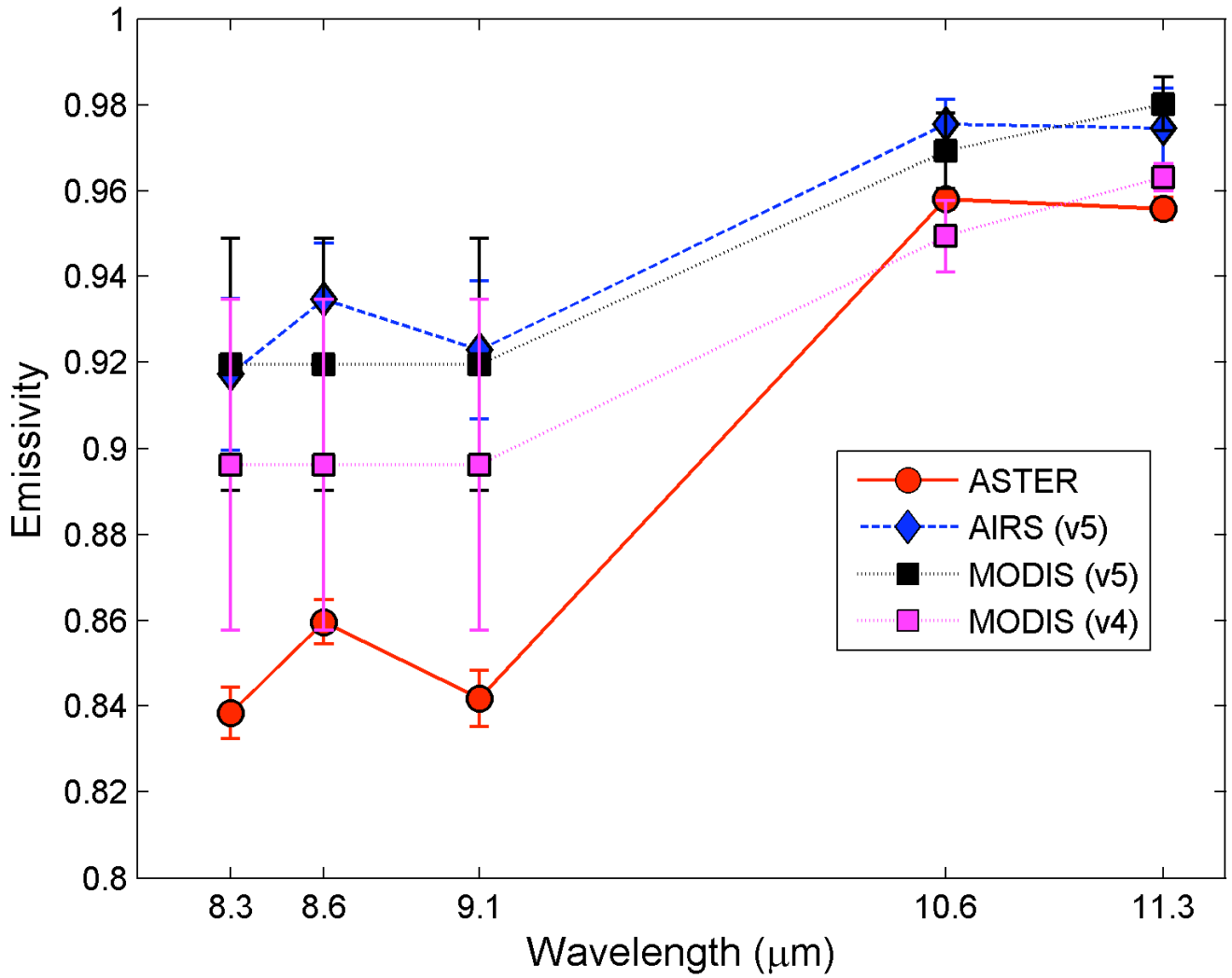
MODIS (MYD11C3 V5) minus AIRS Mean Summer Emissivity Comparisons



Low-Emissivity (Quartz)

All pixels with ASTER ε at 8.3 μm <0.85

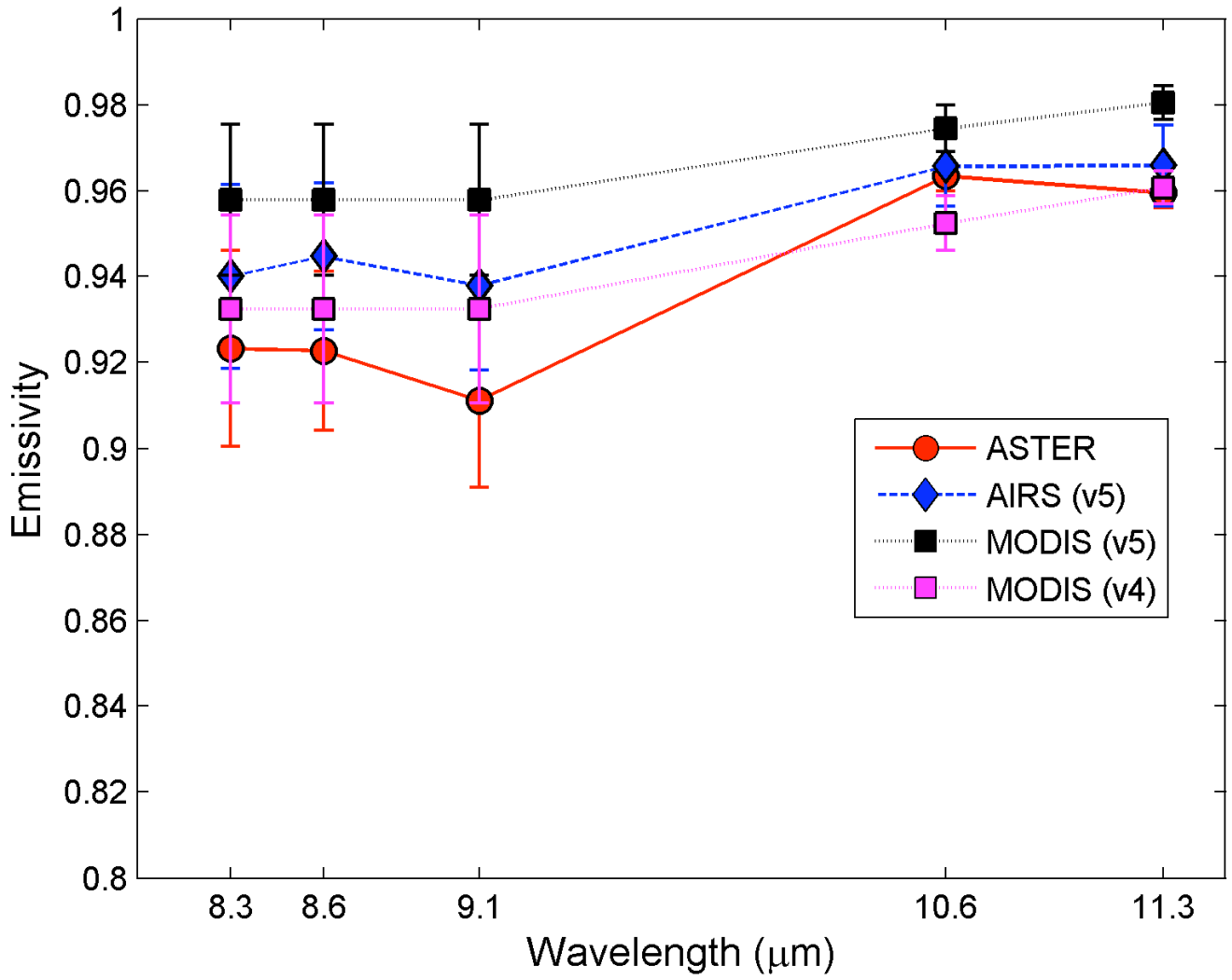
10 pixels



Mid-Emissivity (Mixed)

All pixels with 0.85 < ASTER ε at 8.3 μm < 0.95

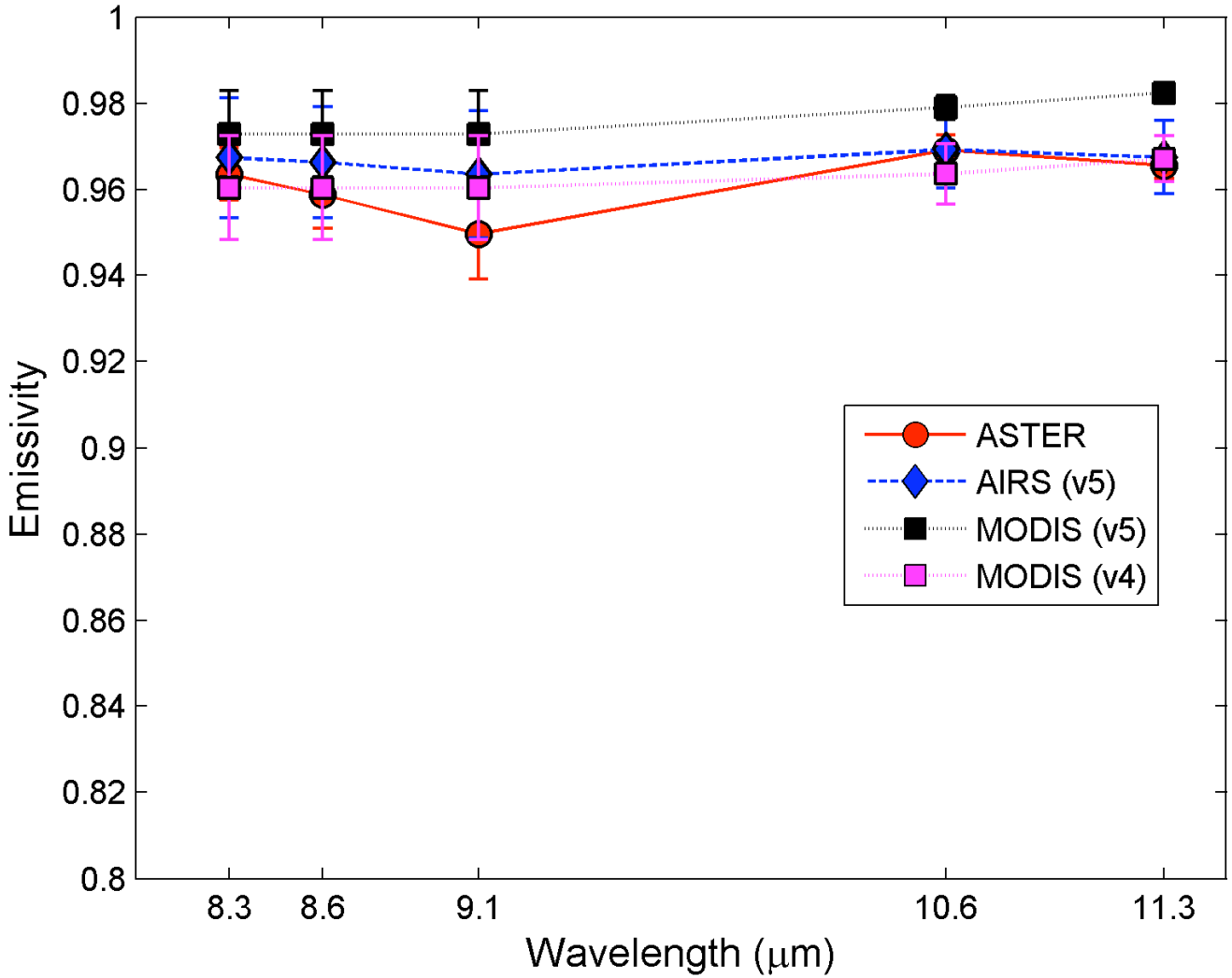
240 pixels



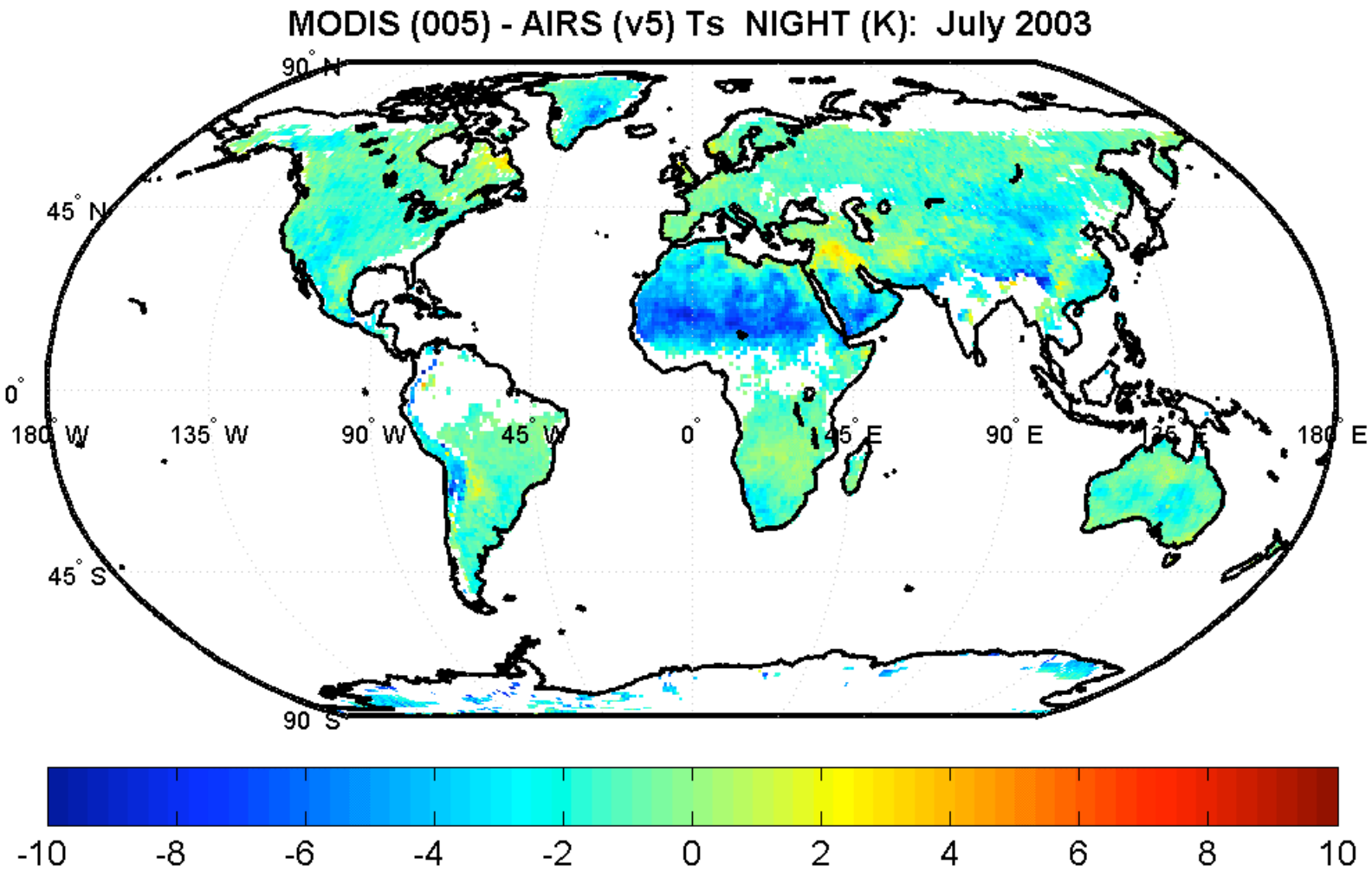
High-Emissivity (Vegetation/Water)

All pixels with ASTER ε at 8.3 μm > 0.95

259 pixels



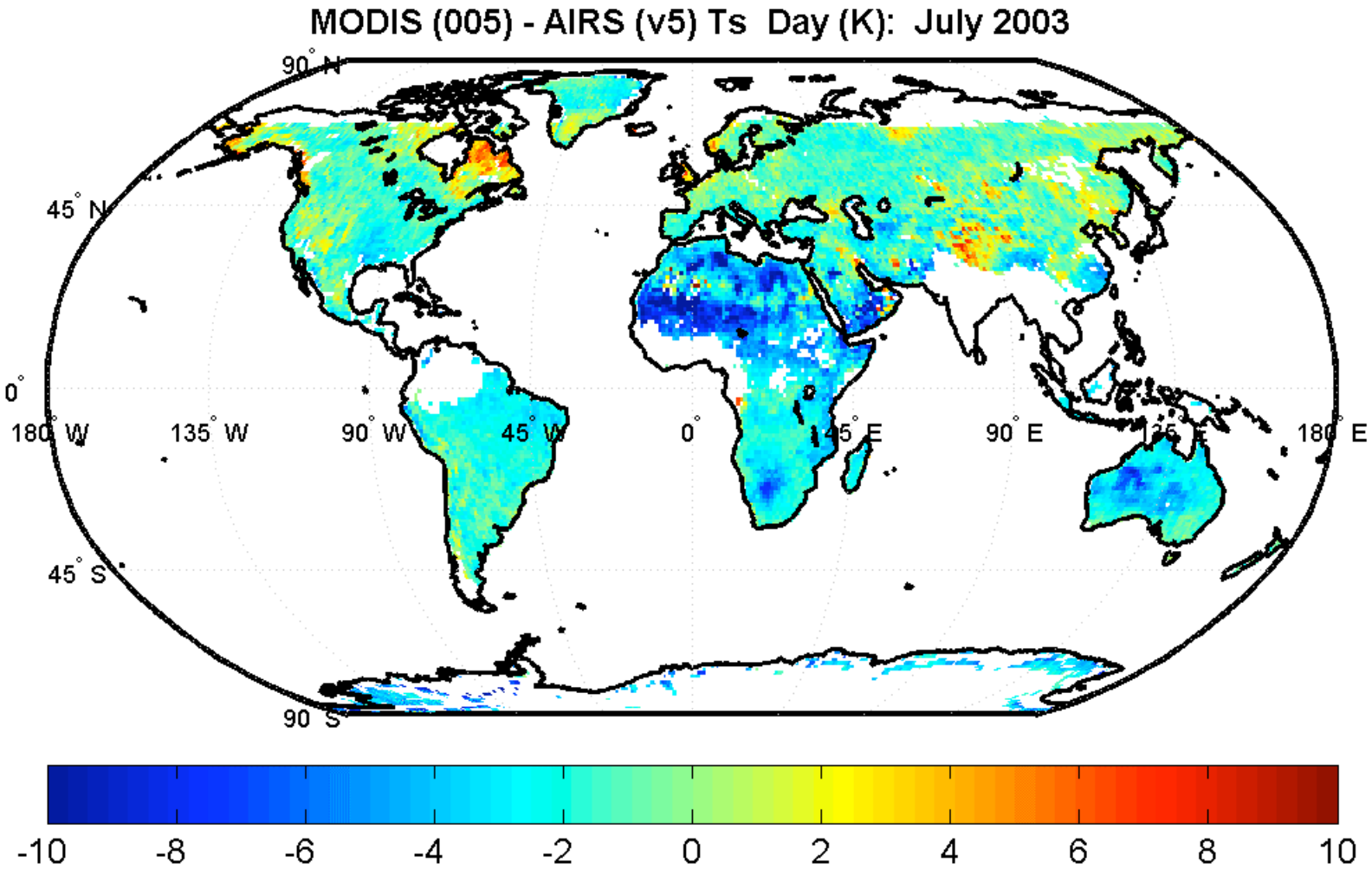
MODIS – AIRS NIGHT



Barren land shows MODIS cold bias (collection 005) up to 8 degrees.

* Knuteson

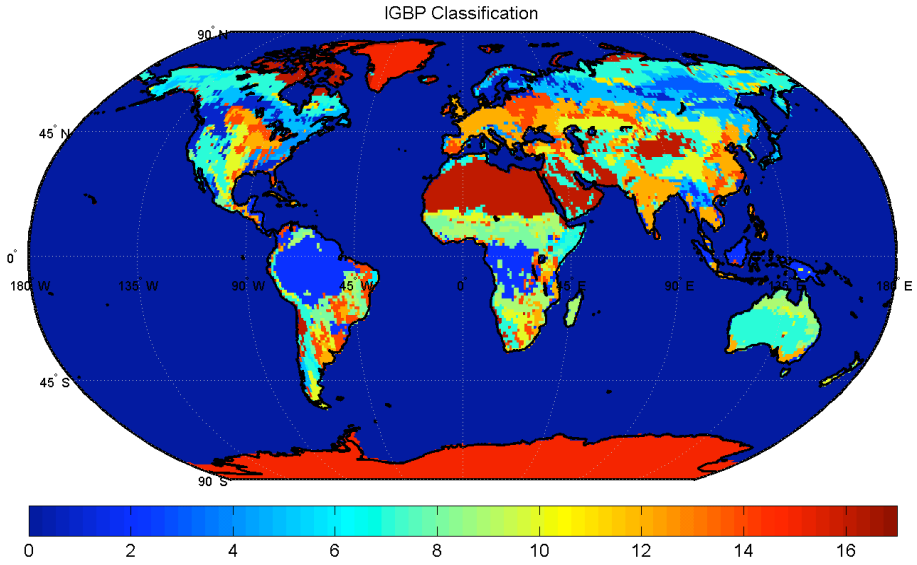
MODIS – AIRS DAY



Barren land shows MODIS cold bias (collection 005) up to 10 degrees.

* Knuteson

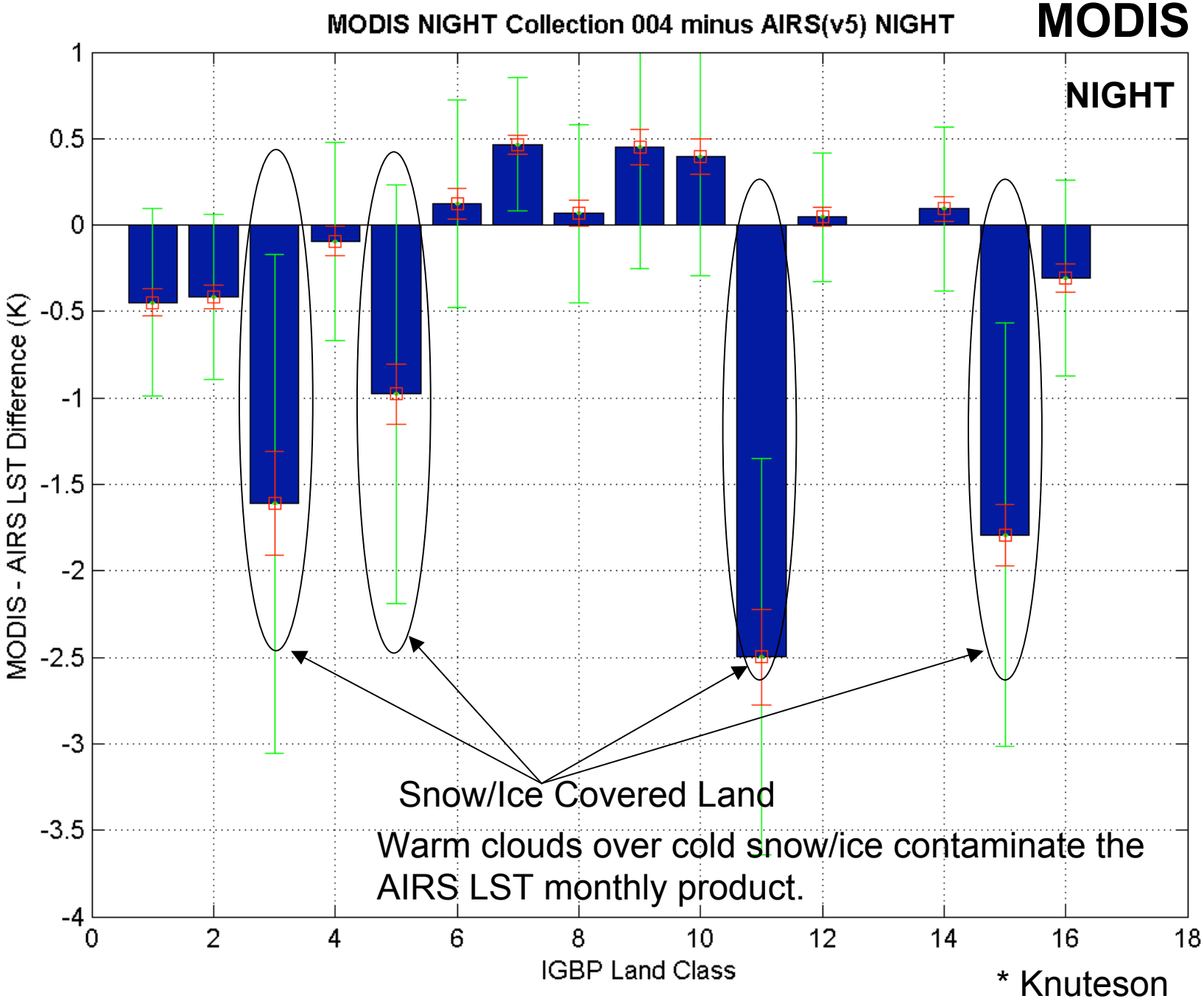
Use Land Classes (IGBP) to group the global data by land type for statistical analysis.



IGBP CLASS ID	IGBP CLASS Description
0	Water Bodies
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Missing Data

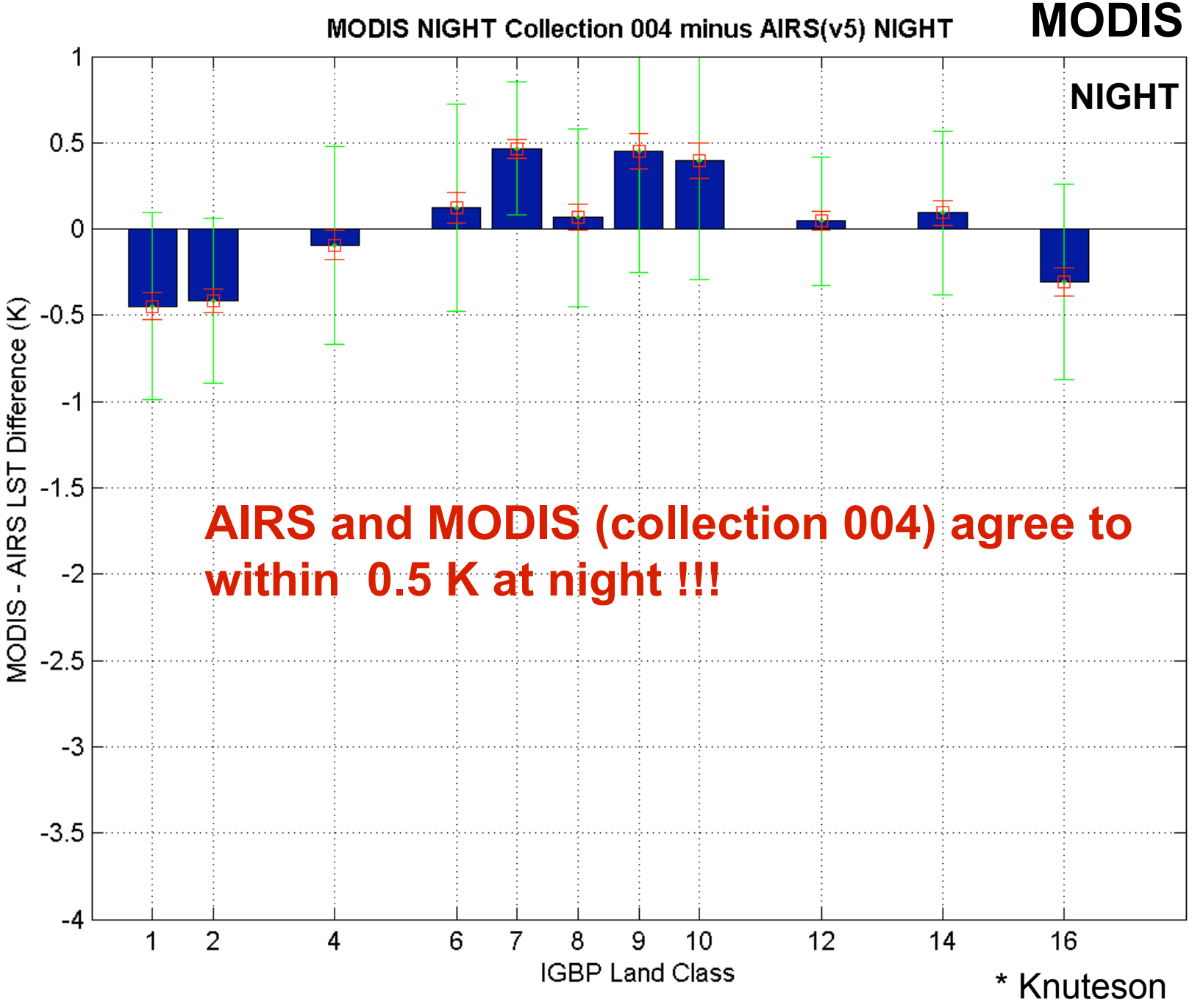
* Knuteson

MODIS 004

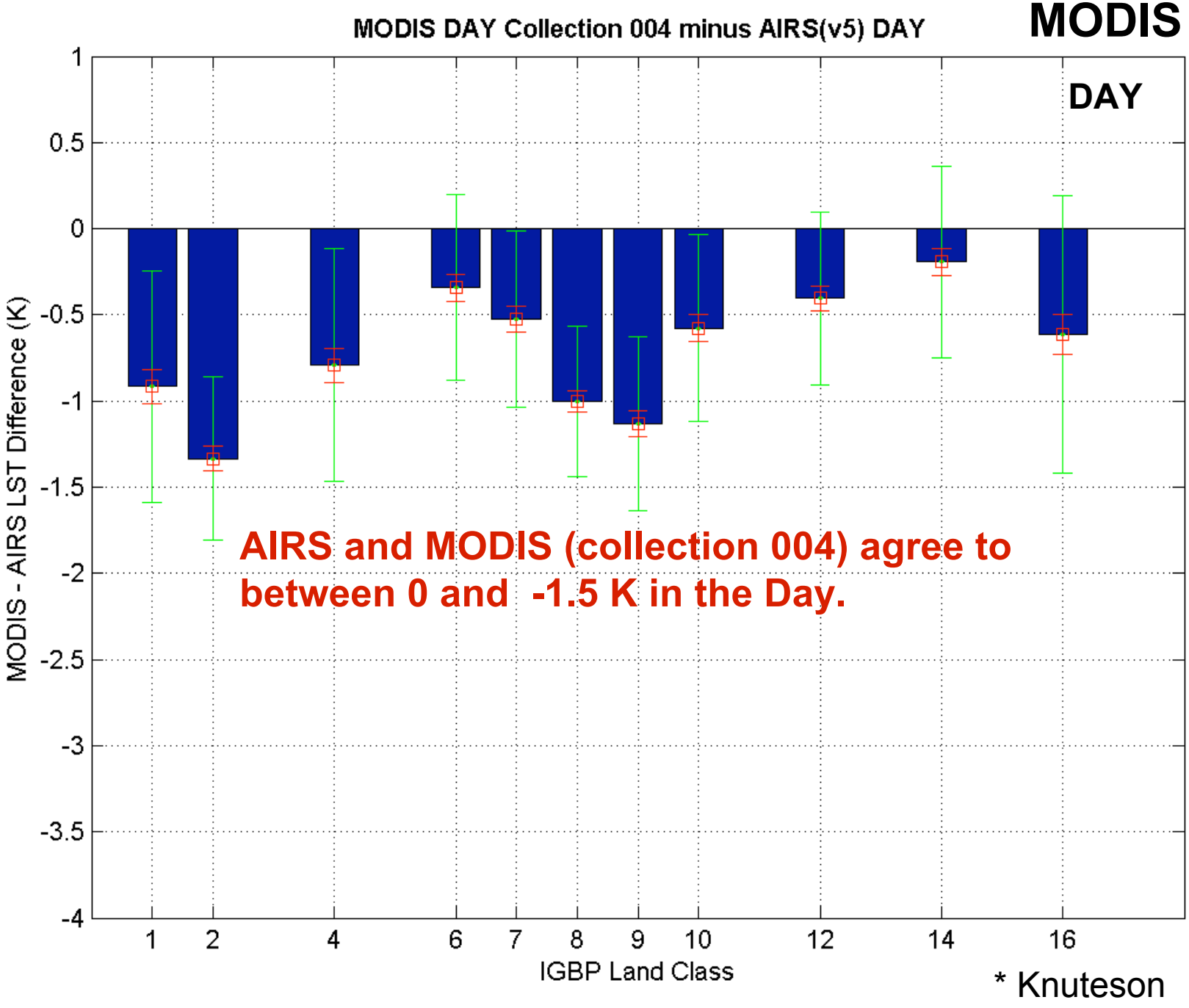


* Knuteson

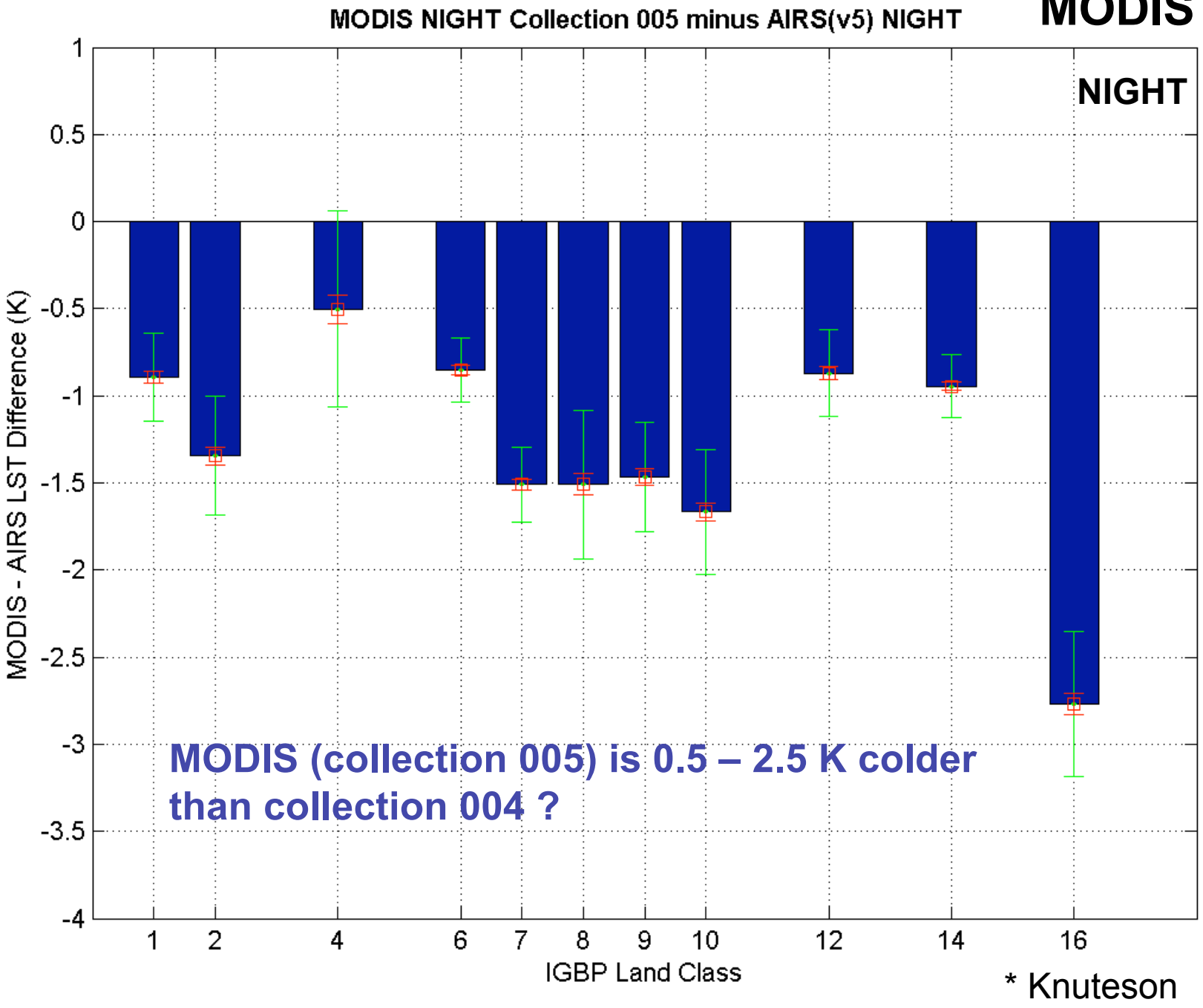
MODIS 004


MODIS NIGHT Collection 004 minus AIRS(v5) NIGHT
NIGHT
MODIS - AIRS LST Difference (K)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
2
4
6
7
8
9
10
12
14
16
IGBP Land Class
AIRS and MODIS (collection 004) agree to within 0.5 K at night !!!
* Knuteson

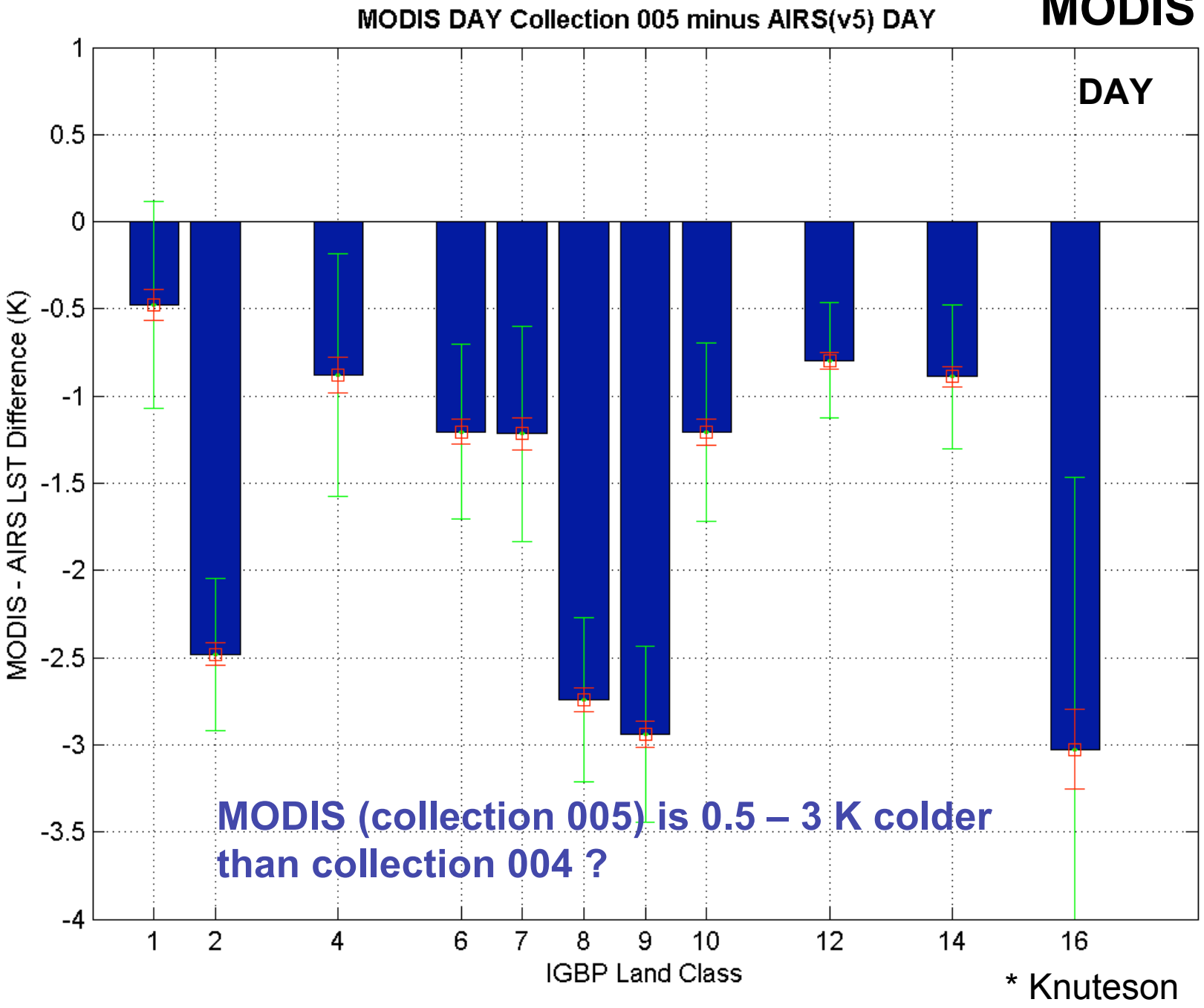
MODIS 004


MODIS DAY Collection 004 minus AIRS(v5) DAY
DAY
MODIS - AIRS LST Difference (K)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
2
4
6
7
8
9
10
12
14
16
IGBP Land Class
AIRS and MODIS (collection 004) agree to between 0 and -1.5 K in the Day.
* Knuteson

MODIS 005


MODIS NIGHT Collection 005 minus AIRS(v5) NIGHT
NIGHT
MODIS - AIRS LST Difference (K)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
2
4
6
7
8
9
10
12
14
16
IGBP Land Class
MODIS (collection 005) is 0.5 – 2.5 K colder than collection 004 ?
* Knuteson

MODIS 005


MODIS DAY Collection 005 minus AIRS(v5) DAY
DAY
MODIS - AIRS LST Difference (K)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
1
2
4
6
7
8
9
10
12
14
16
IGBP Land Class
MODIS (collection 005) is 0.5 – 3 K colder than collection 004 ?
* Knuteson

Summary and Future Work

- ASTER validation results
  - <0.5 % rocks/sand, 1-3% over vegetation/water
- AIRS (v5) and ASTER emissivity differences
  - <1.5% over vegetated and mixed areas
  - Up to 7% over desert areas.
- Up to 10% differences between MODIS v4 and v5 over barren areas
- Complete L3 ASTER emissivity dataset for North America
- Address sampling problem
- Compare diurnal and seasonal emissivity differences
- Make comparisons with Joel's new surface retrieval results (v6?)
- Use ASTER emissivity for AIRS first guess instead of Land Cover Classification a priori?

Low-Emissivity (Quartz)

All pixels with ASTER emissivity at 8.3 μm <0.85

Wavelength	8.3 μm	8.6 μm	9.1 μm	10.6 μm	11.3 μm
Mean Bias					
ASTER – AIRS (50 km)	-0.071	-0.067	-0.071	-0.015	-0.021
ASTER – MODIS (5 km)	-0.079	-0.056	-0.076	-0.009	-0.024
MODIS – AIRS (50 km)	0.005	-0.011	0.001	-0.007	0.003
Std Dev					
ASTER – AIRS (50 km)	0.028	0.028	0.033	0.009	0.012
ASTER – MODIS (5 km)	0.016	0.015	0.016	0.008	0.005
MODIS – AIRS (50 km)	0.022	0.024	0.023	0.011	0.016

Mid-Emissivity (Mixed)

All pixels with 0.85 < ASTER emissivity at 8.3 μm < 0.95

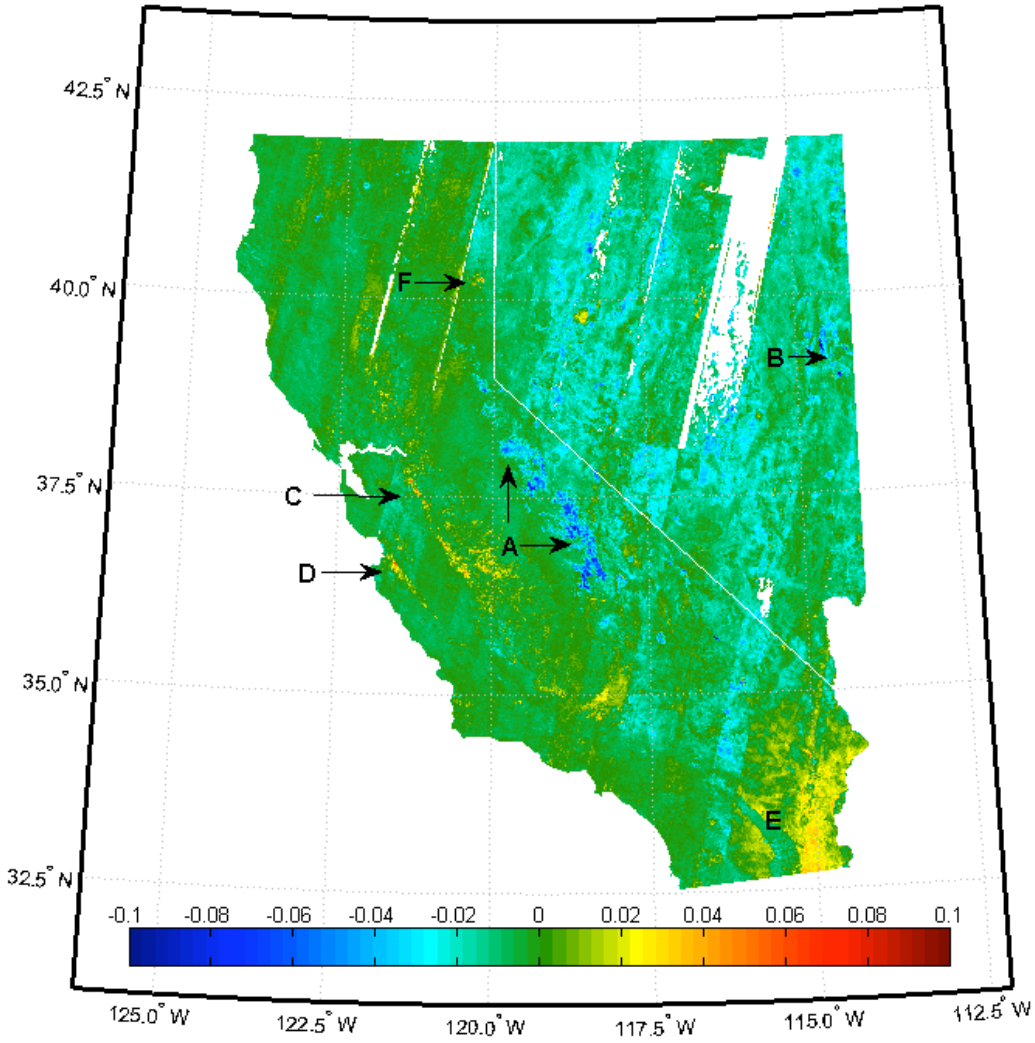
Wavelength	8.3 μm	8.6 μm	9.1 μm	10.6 μm	11.3 μm
Mean Bias					
ASTER – AIRS (50 km)	-0.017	-0.023	-0.027	-0.002	-0.006
ASTER – MODIS (5 km)	-0.038	-0.038	-0.050	-0.011	-0.021
MODIS – AIRS (50 km)	0.018	0.013	0.022	0.009	0.015
Std Dev					
ASTER – AIRS (50 km)	0.022	0.019	0.020	0.009	0.011
ASTER – MODIS (5 km)	0.018	0.015	0.016	0.005	0.005
MODIS – AIRS (50 km)	0.018	0.017	0.018	0.010	0.010

High-Emissivity (Vegetation/Crops)

All pixels with ASTER emissivity at 8.3 μm > 0.95

Wavelength	8.3 μm	8.6 μm	9.1 μm	10.6 μm	11.3 μm
Mean Bias					
ASTER – AIRS (50 km)	-0.003	-0.008	-0.014	-0.001	-0.002
ASTER – MODIS (5 km)	-0.008	-0.013	-0.022	-0.010	-0.017
MODIS – AIRS (50 km)	0.006	0.007	0.010	0.010	0.015
Std Dev					
ASTER – AIRS (50 km)	0.012	0.011	0.012	0.008	0.009
ASTER – MODIS (5 km)	0.010	0.010	0.012	0.004	0.004
MODIS – AIRS (50 km)	0.017	0.016	0.018	0.009	0.009

ASTER Summer minus Winter mean emissivity



ASTER L3 Emissivity Validation

- High spatial resolution (100m) makes validation possible
- Homogenous areas with known composition needed
- Samples measured in lab using FTIR
- Reflectance converted to emissivity and convolved to ASTER bands
- Geologic Samples
  - Quartz-rich Algodones dunes, southeastern CA
  - Carbonate-rich fan deposit, Cuprite NV
  - Stovepipe Wells dunes, Death Valley, CA
- 10 samples taken in 500x500m grid
- 2x2 ASTER pixels (1 pixel = 180 m)

Outline

- ASTER overview
- New ASTER L3 Emissivity Product
- ASTER Emissivity Validation results
- AIRS and ASTER Emissivity Comparisons
- MODIS and ASTER Emissivity Comparisons
- AIRS and MODIS Global LST Comparisons
- AIRS and MODIS Global Emissivity Comparisons
- Summary and Future Work

➢ MODBF – Seemann Baseline Fit LSE Database

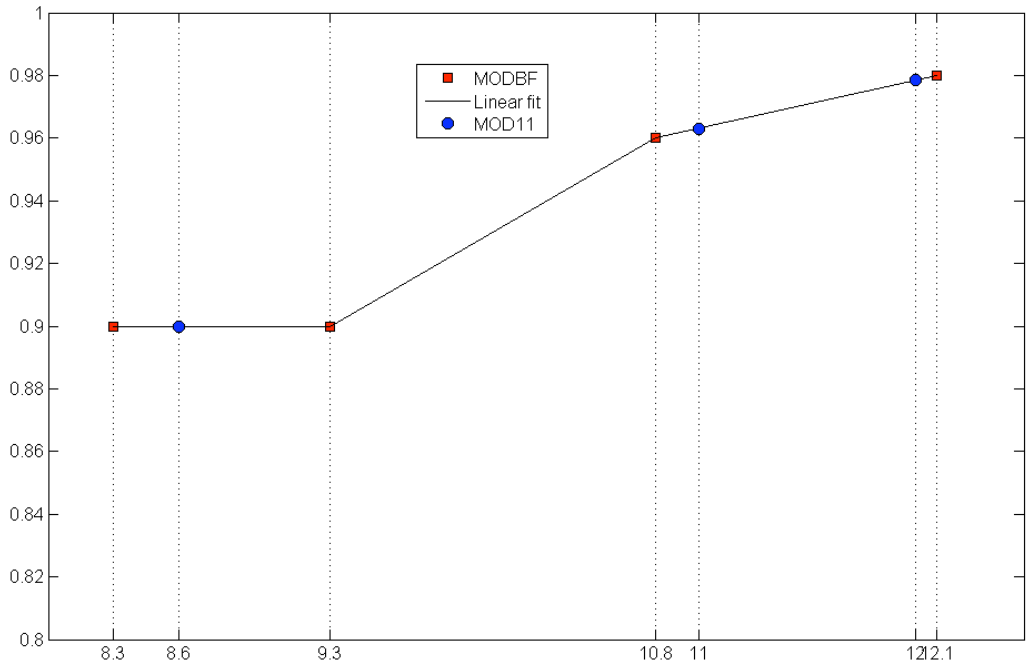
- Characterized by model with inflection points at 8.3, 9.3, 10.8 and 12.1 µm in TIR

➢ MOD11 – MODIS LSE Product

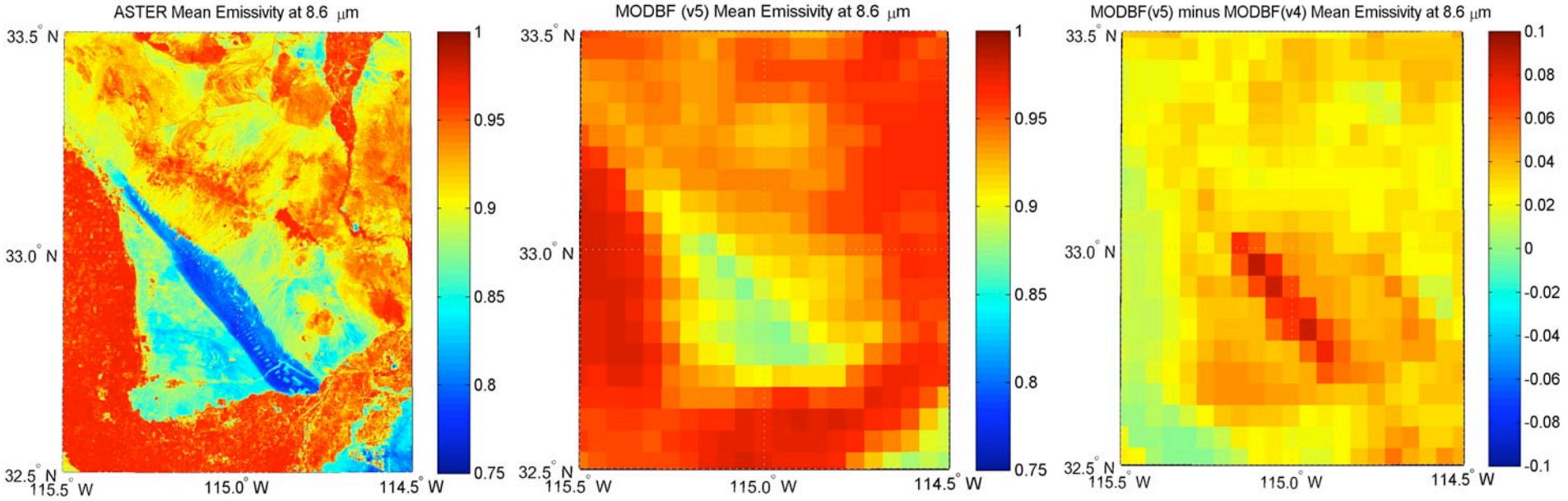
- Day-night emissivity retrieval with values at 8.6, 11 and 12 µm in TIR

➢ MOD11 values at 8.6 um are assigned to inflection points at 8.3 and 9.3 µm , while MOD11 emissivity values at 11 and 12 µm are used to extend line from hinge points 10.8 and 12.1 µm.

➢ MODBF can be linearly interpolated between inflection points for comparisons with other instruments, eg. ASTER



Algodones Dunes – MODIS v4 and v5 Differences



New ASTER Cloud Mask Algorithm (NACMA)